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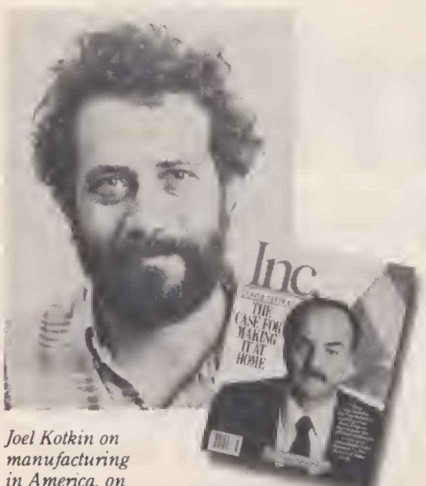

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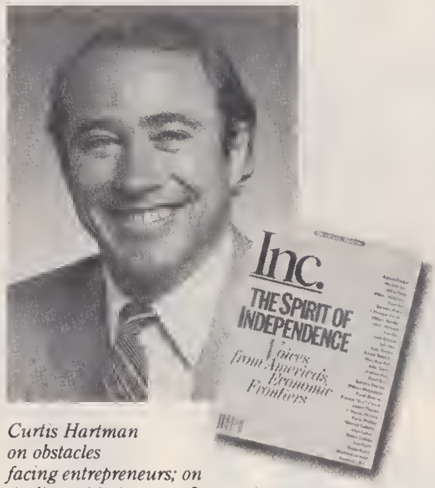

Curtis Hartman on obstacles facing entrepreneurs; on dealing with the press. Inc. senior editor, team leader for coverage of Inc.'s 100 and 500 companies.

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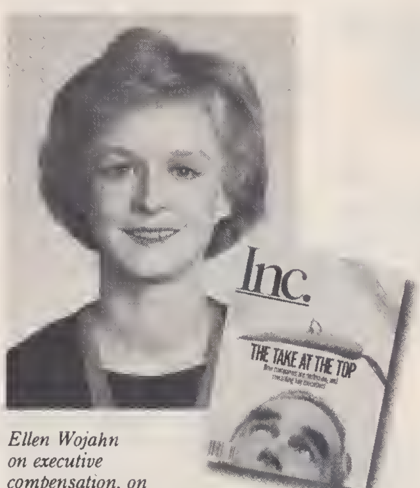

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highTechnology

VOL. 6, NO. 2

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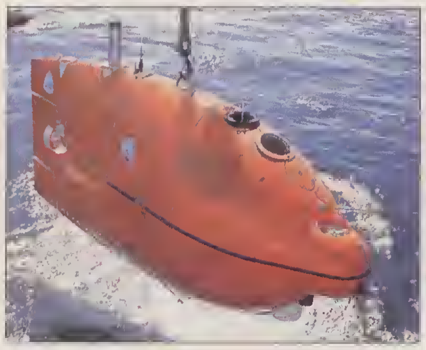

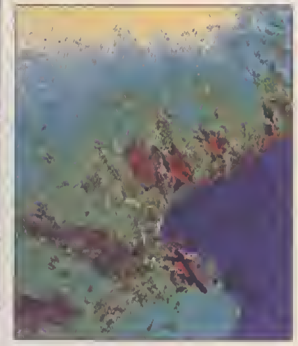

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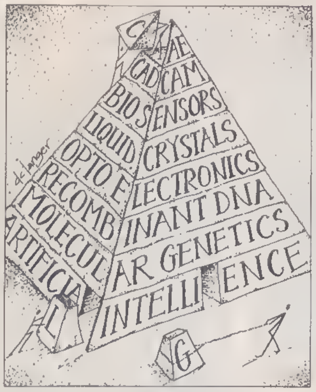

The pyramids of our age: a new set of tools

The greatness of a society is often measured by its public works. The sphinx and the pyramids mark the sophistication of the ancient Egyptians. The Romans are remembered for their complex system of roads and aqueducts. The ancient Greeks live on through their magnificent architecture. The great cathedrals of Europe commemorate the religious fervor as well as the engineering genius of the Middle Ages.

What are the great works that will mark our own times? Surely skyscrapers will literally be monuments to our technology. The great bridges and highway networks, as well as the tunnels soon to be built in Japan and Europe, will be recognized as great technological feats. The flying machines that free us from the confines of the earth and enable us to move out into space will be a tribute to our inventiveness.

But the greatest triumphs of our times may not be our monumental works. Instead, this may be viewed as the era when a set of tools was developed to enable humanity to create a different kind of society. We are living in a new age of exploration—not of unexplored territories, but of systems that can amplify our intelligence, augment our senses, and automate tasks both simple and complex.

It is still early in the voyage, and it is easy to become frustrated at how crude these tools remain in spite of their great potential. Advancing technology promises to enable us to cure most diseases, build far more efficient manufacturing systems, travel farther and faster in greater comfort and safety, live in the oceans and in space, expand our creative abilities, and just have more fun.

But technology alone cannot make a better world. Just as technological advances can enrich our lives, they can also lead to devastation. It is in the political arena that choices must be made about our future directions. Increasing world tensions can shift priorities toward developing weapons of greater and greater destruction rather than tools for a brighter future.

If our era is to be viewed with favor by future historians—indeed, if society is to survive at all—we must find ways to reduce distrust and hostility and avoid the insanity of nuclear war. Technology promises to give us a monumental new set of tools, but their ultimate greatness will depend more on the wisdom and skills of their users than on the brilliance of their creators.

Robert Haavind

Robert Haavind

D.C. LANGER

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Published monthly by ***High Technology Publishing Corp.,*** 38 Commercial Wharf, Boston, MA 02110.

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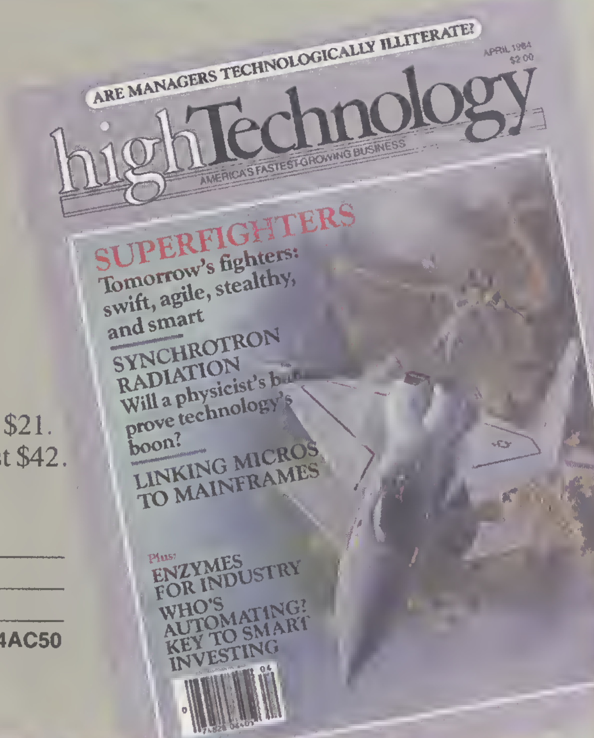

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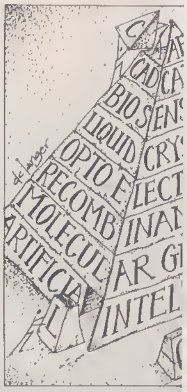
David Himmelsbach
Himmelsbach & Co.
Honolulu, Hi.

Chronar's 1-foot-square photovoltaic panels produce power for driving electrical devices in remote areas, such as the water pump shown above.

We welcome comments from our readers. Please address letters to Editor, High Technology, 38 Commercial Wharf, Boston, MA 02110.



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D C LANGER

LETTERS

How to lure talent

As a researcher in the defense technology industry, I read with interest your December 1985 Opinion, "The price we pay for our military technology strategy: a brain drain." I agree that defense technology is a large drain on the U.S. economy, but I do not believe that the measures you suggest will attract talented engineers and scientists to basic industries.

Higher pay scales and more freedom to explore new ideas are not enough. No fancy research program or high salary would lure me to Big Steel or Big Oil. If I worked in these industries, my lab would probably disappear as soon as short-term profits satisfied a vice-president's career ambitions. These industries should decide if they are in the business of making steel and oil or just in the business of making money.

Futhermore, why would anyone with talent and pride want to work in an industry that spoils its surroundings and has to be sued to clean things up?

The ways to lure talent may be found by examining successful companies like IBM, Apple Computer, Burroughs, Du Pont, Dow Chemical, and 3M. All are "willing to go for far-out concepts," establish offices in pleasant locations, and treat their employees like special resources.

Joseph Reynolds, Principal Scientist
Analysis and Applied Research Div.
Tracor
Austin, Tex.

Test flights yes, test planes no

Your article "Controversy swirls around experimental aircraft" (Nov. 1985, p. 78) confuses my views on test planes with those on test flights. We certainly do not need experimental aircraft to build new commercial transports. Nor do we need another X-series; we can get almost all the necessary information by piggybacking experiments on existing aircraft and by computer simulations. But I would never suggest abandoning the practice of test-flying planes before they are delivered to the customer. The surprises uncovered by such flights may indeed be few in number, but they can be of critical importance.

John M. Swihart, Vice-President
Airplane Market Analysis
The Boeing Company
Seattle, Wash.

Joint venture in photovoltaics

I have followed the enormous progress of AFG Industries for several years and was gratified to see the article "Specialty glass gives a clear view to profits" (Nov. 1985, p. 18). You mention AFG's involvement in the exciting area of photovoltaics, but do not include what may be its most significant commercial activity in that area.

Chronar's 1-foot-square photovoltaic panels produce power for driving electrical devices in remote areas, such as the water pump shown above.

In August of last year, AFG entered into a joint venture with Chronar Corp. and the Southern Company to build a manufacturing plant that will produce amorphous silicon photovoltaic cells with a combined capacity of 1 megawatt annually.

AFG's capabilities in the processing of large glass plates is matched in this project with Chronar's amorphous silicon technology, which uses a glass substrate.

The Southern Company has already indicated that the next step is a 200-megawatt, fully automated plant.

Joshua Z. Levine
Port Washington, N.Y.

A mistaken leading LAN

I would like to offer a correction to your article "PCs start talking over links and LANs" (Nov. 1985, p. 37).

IBM has not brought out a broadband network called "PC-Net." PCnet is a trademark of Orchid Technology of Fremont, Cal., while IBM's own local-area network for PCs is called "PC Network."

PCnet, created in 1982, was the first LAN available on the market for IBM PCs; even IBM bought Orchid's PCnet for its network installations before announcing its first LAN for PCs last year. PCnet is also licensed by AST Research, Santa Clara Systems, and the Qume division of ITT.

Jamie G. James
The James Agency
Los Angeles, Cal.

Recycling obsolete subs

I was most interested in your Perspective on transarctic submarine transport (June 1985, p. 70), although I consider $250 million per tanker an optimistic estimate for untested technology. Perhaps there is an alternative.

The Navy is retiring obsolete nuclear submarines because they are too noisy for front-line service. These vessels have decades of service life left. Wouldn't it make sense to demilitarize the obsolete hulls and use them for fuel transport?

David Himmelsbach
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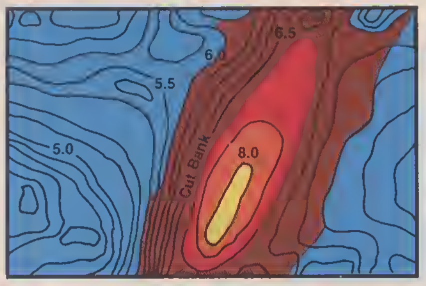

Coal-seam plot made with Radio Imaging Method reveals increasingly rocky conditions (brown to yellow), which could hinder mining.

Law firms focus on high tech

While high tech law isn't a recognized specialty like corporate, international, or tax law, it may just be a matter of time. A growing number of law firms are establishing technology departments staffed by attorneys with scientific expertise. Their main purpose is to deal with legal questions concerning proprietary technology. But they also serve other important functions, such as translating technical language into lay terms for the firm's other lawyers or, in some cases, judges and juries.

Large R&D investments by high tech companies have led to a proliferation of trade-secrets cases, according to attorney Robert F. Scoular, a former aerospace engineer who heads a technology and computer group at Bryan, Cave, McPheeters & McRoberts (Los Angeles). Whether a company should protect its intellectual property as a trade secret or should file a patent or register a copyright is an intricate question, says Scoular—and the general practitioners who draft incorporation papers for many start-ups may not be conversant with such matters.

Some free legal advice: If management chooses the trade-secret route, Scouler's firm recommends a program of mandatory nondisclosure agreements for employees and potential customers and of putting all sensitive documents under lock and key.

Coal miner's plotter

An electromagnetic survey technique that evaluates coal deposits much as medical CT scans probe the body promises to enhance mining safety and save millions of dollars annually. The Radio Imaging Method (RIM), developed by Stolar in Raton, N.M., solves a long-standing problem: locating and defining faults, sandstone channels, and other anomalies in coal seams before mining begins. Other approaches, such as radar and seismic surveying, have generally proved inadequate or too expensive. As a result, companies often have to gamble that hidden trouble spots won't slow production, damage costly equipment, cause cave-ins, or even force abandonment of the mine.

RIM can be used within a mine to study "long-wall panels," blocks of coal 600 feet wide and nearly a mile long that are surrounded by excavated corridors from which mining takes place. (A single panel can be worth $30 million and take a year to mine.) RIM surveys can also be done from holes drilled from the surface to evaluate prospective mining sites. A transmitter sends electromagnetic waves of a specific frequency through the seam, to be picked up by a receiver. The signals, which lose energy when they encounter rock or other anomalies, are analyzed by computer, using algorithms developed by company cofounder Larry Stolarczyk, and plotted as a contour map.

Several major mining companies now use RIM routinely; a typical survey costs about $20,000. Recent tests suggest that RIM will also prove valuable in locating faults that contain commercially important hard-rock minerals. However, the company isn't revealing details until additional patents are granted.

Expert system does financial planning

Vendors in the artificial intelligence field offer a variety of "tool-kit" products to assist in the building of expert systems, but few complete expert systems are commercially available. Applied Expert Systems, or Apex (Cambridge, Mass.), has entered this virgin territory with PlanPower, a system that performs personal financial planning. Apex is marketing the product, which is sold bundled with Xerox's new 1186 AI workstation for just under $50,000, to large brokerage firms and to independent financial planners. PlanPower can either assist in evaluating a client's financial needs and options or do virtually the whole planning task, including the formulation of recommendations and the printing of a detailed financial plan.

The system contains a database of facts about more than 200 classes of objects—such as stocks, insurance policies, or family members—and "understands" the relationships between objects. Another element, an "expert framework," encodes rules, analysis techniques, and decision-making procedures used by financial planners. This knowledge—the equivalent of about 6000 "if/then" rules—interacts with data on specific clients and with facts in the database to formulate recommendations about everything from how much life insurance they should carry to how they should prepare for their children's college expenses. A language called Computed Text allows PlanPower to print out a comprehensive report in ordinary English.

Tickling the conductive rubber: Notebender keyboard senses the force of a player's fingertips.

Chemical reactions going solar?

A molecule developed at Argonne National Laboratory (Argonne, Ill.) may one day use solar energy to drive a variety of common chemical reactions. Consisting of one molecule each of quinone, dimethylaniline, and porphyrin (the chemical "parent" of the chlorophylls), it mimics a key step in plant photosynthesis by converting 70% of incident sunlight into chemical energy and briefly storing it. The appeal of such an energy source is its specificity; unlike heat energy—which is distributed throughout the reaction chamber, often creating undesirable byproducts—it would be used only by molecules taking part in the reaction.

When sunlight strikes the Argonne molecule, it causes a series of electron transfers between the three components. The result, says chemist Michael Wasielewski, is a molecule with a positive charge at one end and a negative charge at the other—an energy storage device that could supply electrons to neighboring reactants. In its present form, the new molecule stores energy for only about 2 millionths of a second, after which it once again becomes electrically neutral. While this is sufficient for many chemical reactions, Wasielewski hopes to extend the storage to several milliseconds, perhaps by adding some more steps before neutrality is restored.

The molecules may eventually be applied in some types of oxidation-reduction reactions, which proceed by interatomic electron transfer. Such reactions are used throughout the chemical industry—in the production of hydrochloric acid, for example, and in the reduction of iron oxide ores to metallic iron.

Fiber optics simplifies auto wiring

As automotive electrical systems get fancier, the wiring harness that carries power and control signals is becoming harder to install, as well as more trouble-prone. Now GM is starting to replace this jumble of cable with fiber optics. In the 1987 Pontiac ST-6000, controls mounted conveniently on the steering wheel will send lightwave pulses through fibers to activate such items as lights, radio, power windows, and door locks, says Wesley A. Rogers, head of Electronic Development Inc. (Grosse Pointe, Mich.).

Signals from multiple controls will be merged (multiplexed), allowing a pair of fibers to do the work of a fat bundle of wires. Besides saving space and weight, optical fibers are immune to electromagnetic interference (EMI). Metal wires, by contrast, act as antennas for EMI; present GM cars require up to 45 electronic filters to prevent such EMI effects as the seize-up of electronic brakes.

Because control systems in cars will carry small amounts of data for only a few feet, they can use plastic fibers that are low in performance (providing neither high capacity nor low loss) and relatively thick (up to 1 mm across). These are cheaper and easier to install than the wispy glass fibers used for telecommunications.

Eventually the fiber network might extend into the engine, to better link its proliferating electronics. Although present plastic fibers made by Du Pont and Mitsubishi Rayon can't take the heat under the hood (up to 120° C), Fujitsu has a new fiber that reportedly survives at 125° C.

Force sensors debut in synthesizers

Force sensors appearing on music synthesizers are answering players' demand for more control over the loudness of individual notes. They also hold promise for application in other areas.

Notebender, a new instrument from Key Concepts (Rockport, Mass.), uses keys made of rubber interspersed with small amounts of carbon. The harder the key is pressed, the better it conducts electricity and the louder the note sounds. (It's called Notebender because the keys can slide in and out to "bend" the pitch.)

In addition, keyboards from Sequential (San Jose) and Oberheim (Los Angeles) and a digital drum machine from Linn Electronics (Tarzana, Cal.) use a thin-film sensor that responds similarly. This "force-sensing resistor" can be produced more consistently than conductive rubber, claims Franklin Eventoff, developer of the device and president of Interlink Electronics (Santa Barbara, Cal.).

Eventoff envisions marketing the thin-film sensor for other applications as well. Tracking the pressure of a check-writer's pen, for example, would tip off a bank to a would-be forger, who would be unable to duplicate this invisible effect. And computer graphics tablets could gain an added dimension of control. Pushing harder on the tablet could, say, deepen a color or extend a line.

Bringing "Star Wars" down to earth

Bernard J. O'Keefe
EG&G

Research and development on esoteric systems for fighting wars in space has been going on for at least twenty years, and designs for lasers, rail guns, particle beam weapons, and battle management systems with millions of lines of software have been in the literature for a decade. These projects maintained a sense of purpose in weapons development laboratories, made good copy in the press, didn't cost more than a couple of billion dollars a year, and were justified by the premise that "we should find out what the laws of physics will allow." It was all good fun and scientifically "sweet."

Then, on March 23, 1983, President Reagan made his famous "Star Wars" speech. There was no particular reason to make such a speech. No technological breakthrough had occurred. No specific plan of action was ready. No cost analysis had been prepared. In fact, the President's advisers in such matters were caught flat-footed, and spent the next few weeks searching for technological fig leaves to cover the administration's exposure.

Yet technological considerations did not really matter. The president knew practically nothing of the scientific problems involved, but—consummate politician that he is—he did understand the profound concerns of the American public over Mutually Assured Destruction. The Soviet Union could annihilate us with hordes of accurate and devastating intercontinental ballistic missiles; and the fact that we could do likewise once the holocaust had begun would be of little comfort. Thus the idea that there might be a defense that could counteract these horrible nuclear weapons seemed like a ray of hope. Even though it would not work against bombers, cruise missiles, close-in submarines, or weapons concealed in suitcases, any effort that appeared to obliterate ICBMs seemed worthwhile, no matter what the cost, because they are such powerful and frightening symbols.

Knowledgeable people moved in quickly to pooh-pooh the idea, repeatedly pointing out that the defense would not work, that the software requirements were impossible to achieve, and that the strategy would promote a response that would accelerate the arms race and decrease national security. No matter. The idea took on a life of its own, with almost spiritual overtones. It became an act of faith to believe in Star Wars while condemning MAD as immoral.

We can no longer afford, any more than the Russians can, to fritter away our resources on military systems that add nothing to our national security.

Subsequently, most of the believers in the administration have backed off from the wilder claims: They have scrapped the "pop-up" weapons, for example, and have admitted that the practicality of x-ray lasers has not yet been demonstrated. The dignified-sounding Strategic Defense Initiative Organization has now cut back on the chemical laser program as too cumbersome, and is eliminating the Space Surveillance and Tracking System because of its susceptibility to decoys and the Boost Surveillance and Tracking System because the software specifications are unachievable. In short, the plans are being modified to the point where they have begun to sound realizable. Even our allies are scrambling for a piece of the action. As these things have been happening, Star Wars has begun to take on some aspects of scientific respectability. And that is dangerous.

It is dangerous, first of all, because it could upset the present nuclear parity. Why add space to our potential battlefields? Such a new dimension offers no strategic advantage to either side, and will certainly decrease the security of both. But the biggest threat that Star Wars poses to mutual security is not military but economic.

We like to gloat over the troubles of the Soviet system. Clearly, it is difficult for a fully planned economy in today's rapidly changing technological world to be responsive; by the time a plan can be developed and put into effect, the world has changed. But we cannot predict the long-term prospects of communism as an economic system any more than we can be certain that Star Wars will drive the Soviets into bankruptcy trying to play catch-up (which could well be the President's hidden agenda). Ironically, an *improved* Russian economy is in our long-term interests; it would give the Soviet leaders greater flexibility and ensure competition in the marketplace rather than on the battlefield.

Our own economy, however, is also

Bernard J. O'Keefe is chairman of the executive committee of EG&G (Wellesley, Mass.), a diversified technology company. His latest book is Shooting Ourselves in the Foot.

in trouble, as evidenced by our eroding basic industries, diminished competitive strength in global markets, and massive federal budget deficit. Under these circumstances, we must carefully husband our resources, both intellectual and material, in order to develop solutions. We can no longer afford, any more than the Russians can, to fritter them away on military systems that add nothing to our national security. In fact, while we are funneling our R&D into esoteric military projects, our friendly competitors are utilizing their own precious assets in their civilian economies.

There are those who claim that military research will engender civilian fallout (in the benign sense of the word), as indeed it did after World War II. But things are different now. At that time, civilian R&D had ceased for four years and there was a pent-up demand for the adaptation of wartime technological developments. Today such demand is minimal, and what little there is gets supplied from abroad. Futhermore, as military and space hardware gets more Buck Rogersish, the conversion efficiency to civilian applications gets lower and lower and the turnaround time longer and longer.

We canot be policeman to the world, especially when those we protect are beating our brains in economically. We still have a quarter of a million troops in Germany, forty years after the war, while the Germans are exporting Volkswagens and BMWs to the United States. There are 100,000 American troops in Japan, while there are 100,000 Japanese businessmen in the U.S. If these nonproductive forces—men and women at the peak of their vitality—were put to work on projects of direct economic benefit, wouldn't we be a lot better off?

Yet we now prepare to go off into another dimension of folly, spending perhaps trillions of dollars on a dubious quest. Meanwhile, our allies—who will carry only a minuscule portion of the burden—will become stronger competitors than ever. And the Russians, who have a lot less to lose, will watch us wane as an economic and military power.

Let's bring Star Wars back to earth. Let's bring it back to what it was and should be—a long-range R&D program of modest proportions. And let's allocate our trillions to more fruitful endeavors.

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BUSINESS STRATEGIES

Grumman:
AEROSPACE FIRM GOES HOME AGAIN

Grumman, one of the aerospace industry's pioneers, has been a builder of military planes since the 1930s and a maker of major space systems such as the lunar module that set the first men on the moon in 1969. But attempts at broad diversification drew the company away from its original business strongholds in recent years.

Today, Grumman, based in Bethpage, N.Y., is back in the military business in a big way, as evidenced by its successful bid for a $657 million design contract for the military's Joint Surveillance Target Attack Radar System, called J-STARS. And it's back in the space business, although not as heavily as before. As a subcontractor to all four teams working on the proposed NASA space station, a subcontractor to Lockheed for Space Shuttle launches at Kennedy Space Center, and builder of the Shuttle's delta-shaped wings, Grumman derived 10% of its $2.6 billion 1984 revenues from space-related business.

"Grumman is reinvesting in aerospace with a vengeance after a decade of painfully unsuccessful endeavors," says Wolfgang Demisch, an aerospace analyst for First Boston Corp. Ill-fated ventures in areas such as solar energy and mass transit culminated in its acquisition of the Flxible bus company, whose fleet for the New York City transit system developed such severe mechanical problems it was eventually removed from service. A chastened Grumman, says Demisch, "is essentially returning to its roots."

"But our biggest thrust," says company president George M. Skurla, "is toward becoming more of an electronic systems house." This is perhaps inevitable in an age when military aircraft, such as the company's supersonic F-14 and the experimental X-29, are essentially airframes wrapped around electronic subsystems. Even its older line, like the 20-year-old E-2C Hawkeye, has changed dramatically inside. "In the old days," recalls Skurla, "the E-2C was just an airplane with a radio in it. But today, it contains 12,000 pounds of black magic" and has a $35 million price tag. Last year, Grumman also signed a $1.14 billion contract with the Navy for the first stage of a $10 billion program to add new radar to its F-14 and A-6 attack planes and replace outdated analog systems with digital electronics.

In September, when Grumman announced it had won the J-STARS contract against competition like Hughes Aircraft and Westinghouse, the company further increased its commitment to electronics by unveiling plans for a new division in Melbourne, Fla., exclusively for developing sophisticated military electronics gear. In addition to J-STARS, the company has several other new electronics contracts, including one with the Army in another growing market for the company—computerized battlefield test equipment. Grumman also has contracts for Strategic Defense Initiative projects and is rumored to be involved in the supersecret Stealth project to design electronic systems that render jet fighters invisible to enemy radar. Skurla reports that the company presently derives 35% of its revenues from electronics and aims to raise that figure to 50%.

Grumman's strategic move toward electronics is paying off, says David Lang, an asset manager for Lehman Management and past president of the New York Society of Aerospace Analysts. But he doubts that the company will stray far from its basic business. "It makes a lot of sense for them to broaden their market opportunities" with programs like J-STARS, says Lang, "but updating the F-14 and A-6 is really more important." Building airplanes, he says, is still "Grumman's bedrock strength."—*Tim Smart*

Electronics will be integral to Grumman's future, says president George Skurla.

Millipore:
FILTER MAKER'S KEY TO SUCCESS: DIVERSITY

Because purity is essential for so many substances used by industries such as chemicals, foods, and pharmaceuticals, Millipore (Bedford, Mass.) has managed to parlay seemingly mundane products like filters into a $365 million business.

Millipore's synthetic membranes and high-performance liquid chromotography (HPLC) systems are hardly ordinary filters, however. The synthetic membranes—basically porous sheets of customized cellophane—can filter out molecules on the order of 10 nanometers in diameter (one-hundredth the size of a particle of tobacco smoke). And HPLC, which involves forcing a liquid at pressures as high as 6000 pounds per square inch through a cylinder packed with silica-based media, can remove particles as small as salt molecules (on the order of 1 nanometer in diameter).

When a batch of liquid is fed into an HPLC apparatus, some dissolved substances are chemically attracted to the media and pass through the cylinder slowly (typically in several minutes), while others pass through quickly. Thus, different substances emerge at different times and in pure form. In many cases, membrane filtration is used to remove large particles before HPLC separates the final products. In addition to being used for purification, filtration systems are also tools for chemical analysis, as in the soft-drink industry, where vendors use HPLC to isolate ingredients of their competitors' formulas.

Millipore is the only company in the field of analysis and purification that is a market leader in both membranes and HPLC, says Linda Miller, an analyst with PaineWebber in New York. Competitors such as Pall Corp. and Gelman Sciences have focused on the

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Millipore's Mulvaney expects a boom fueled by growth in biotech and electronics.

membrane market, while others, including Perkin-Elmer, Varian, and Sweden's Pharmacia, are targeting the HPLC market. Millipore's dual strategy gives it an edge in meeting customers' highly specialized demands, says Miller, thereby helping it capture a third of the annual $1 billion worldwide market for both membrane and HPLC products.

However, increased competition in the industry's traditional strongholds—chemical, food, and pharmaceutical analysis and purification—have made it hard for Millipore to improve on or even continue its decade-long annual growth rate of 10–15%. While the company still depends on these markets for 55% of its sales, chairman and CEO Jack Mulvany says Millipore is looking to new markets in the microelectronics and biotechnology industries for future growth.

Sales to semiconductor manufacturers now account for 15% of Millipore's revenues—a figure Mulvaney predicts will rise to 25% by 1990. In addition to purifying arsine and phosphine gases used in the manufacturing process, some chip makers are beginning to purify photoresistive and etching chemicals as well, in an effort to increase chip yields. In biotechnology, which currently accounts for 10% of Millipore's revenues, the company projects a 20% figure by 1990 because of anticipated use of genetically engineered organisms in new pharmaceutical, specialty chemical, and agricultural applications. These, in turn, could create booms of their own in filtration products.

An expanding market, however, could also fuel the efforts of a new group of competitors: Japanese chemical-equipment manufacturers. Shimadzu, for one, has already targeted the analysis and purification market and could soon become a major force to contend with, acknowledges Mulvany. But in Millipore's favor, he maintains, is the extreme diversity of the market, which could effectively thwart the low-cost supplier strategy favored by many of Japan's manufacturers. None of Millipore's 5000 products generates even 5% of the firm's revenues, Mulvaney notes, but its support staff must know enough about them all to help a diverse customer base meet often-unique needs. Millipore is hoping its experience in dealing with such a fragmented market will help keep it an industry leader. ***—David H. Freedman***

Alpha Microsystems:

VCRs THAT BACK UP COMPUTER DATA

While computerized files eliminate much of the human error that once plagued corporate record keeping, they create their own brand of worries. Suppose, for instance, that a disk drive were to malfunction and crucial data were suddenly lost. To avoid such catastrophes, most computer users make backup copies of each day's work—even though this may require duplicating expensive hard-disk drives or buying special backup tape drives.

Now, Alpha Microsystems (Santa Ana, Cal.), a maker of small computers, has an alternative for PCs. By adding its $795 Videotrax controller board to IBM PC/XTs, PC/ATs, and look-alikes, one can copy data stored on a hard disk onto standard videocassettes, using an ordinary videocassette recorder. And because most VCRs are programmable, they can be set up to copy late at night, rather than during the workday as conventional backup equipment requires. (A $1599 system, which includes a modified VCR, can be programmed completely from the keyboard.)

Alpha Micro originally developed the Videotrax for its own line of multiuser computer systems, which is sold largely to doctors, dentists, lawyers, and municipalities. The firm decided to adapt the system for the more widely used PC partly "to improve our name-recognition and get people interested in doing other business with us," says company president Richard Cortese.

The technology's five-year history with the company is a point in its favor. "It means it's debugged and it works," says Jim Porter, president of Disk/Trend, a computer research firm in Los Altos, Cal. He reckons that Alpha Micro may need all the ammunition it can get when it goes up against established competition in the backup equipment market, such as Cipher Data Products, the current leader. Cipher is developing a new system for PCs—with IBM's blessing—that uses the standard backup tape cartridges IBM developed for its larger computers. Another problem for Alpha Micro, says Teri Mortola of International Data Corp. (Santa Clara, Cal.), is that the VCR's image as a consumer item may hinder its acceptance in the corporate computer room.

Unfazed, Alpha Micro points to another capability of Videotrax. With a slightly different controller board, the system can convert data into a format that can be broadcast from a commercial TV studio, be received anywhere in the country, and be stored (naturally) by a VCR. "A nationwide retailer, for example, might want to broadcast a daily update on what's available in its warehouse," explains Cortese. It can cost less, he claims, to broadcast late at night, when commercial airwaves are generally unused, than to send data to distant branches via phone lines. Once again, though, Alpha Micro faces stiff competition, in this case from a range of telecommunications carriers spawned by industry deregulation.

Still, with less than $4 million spent on the development of Videotrax, the new product line could strengthen Alpha Micro's balance sheet. As a result of the industrywide slump, the nine-year-old company saw profits of $2 million on sales of $51 million for the year ended in February 1985 turn into red ink over the next two fiscal quarters. Until prospects for computer sales improve substantially, VCRs could help brighten the company's picture. ***—Sarah Glazer***

Underwater robots can perform inspection and maintenance chores, such as repairing an offshore oil well, and can remain submerged for days or weeks.

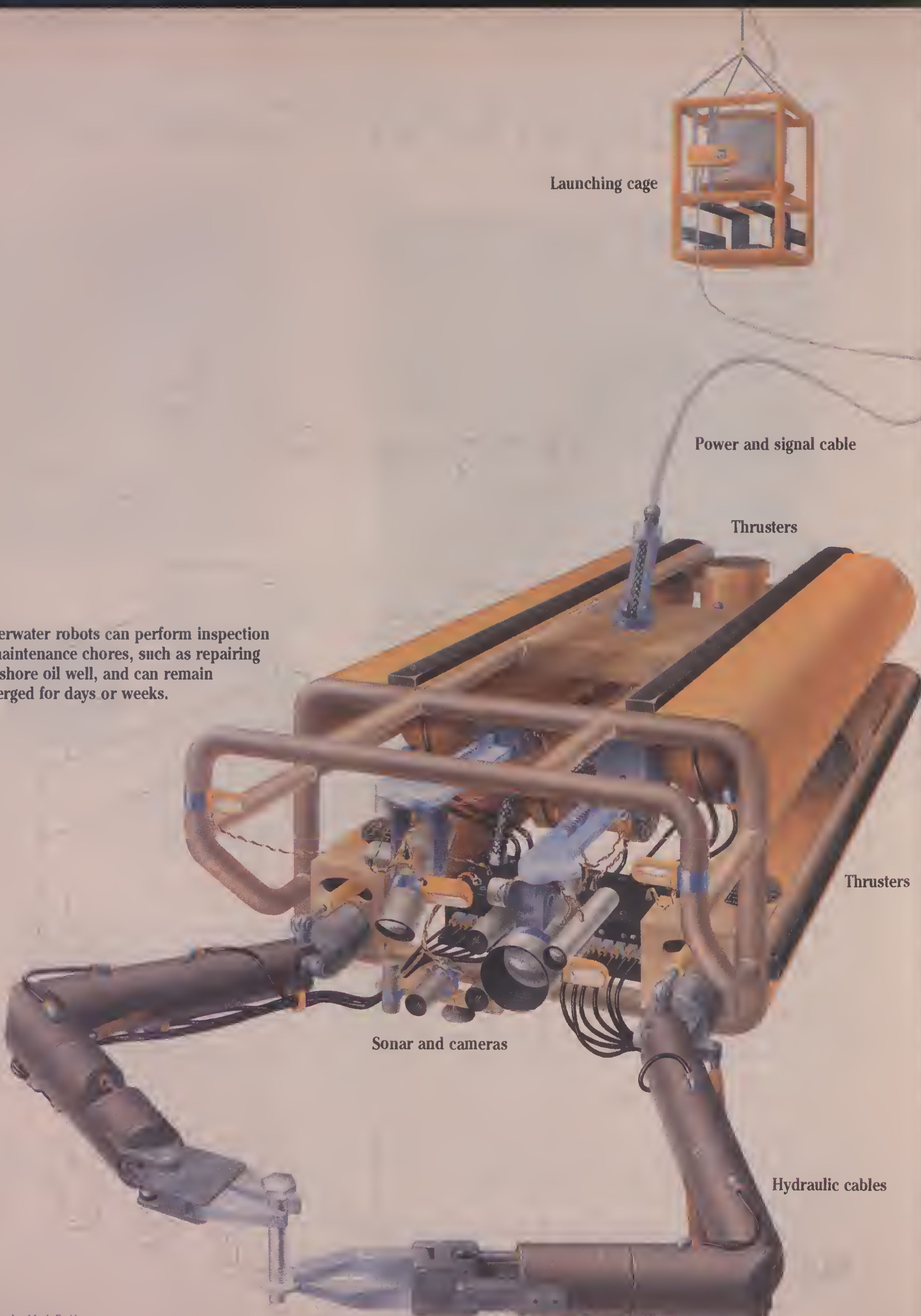

Illustration by Mark E. Alsop

SUBMERSIBLES REACH NEW DEPTHS

by Jonathan B. Tucker

Unmanned subs are plunging into commercial, military, and scientific applications

Small unmanned submarines are causing a quiet technological revolution in the field of ocean engineering. Although such vehicles have been in use for more than 20 years, recent advances in electronics, communications, and robotics have led to a new generation of remote-controlled undersea craft that can dive deeper, see better, stay down longer, and perform more complex tasks than ever before.

Unlike human divers, who can routinely dive only to about 1000 feet, unmanned submersibles can be deployed at great depths with no risk to human life. And while today's manned minisubs must surface after a maximum of eight hours for servicing and a change of crew, the endurance of unmanned submersibles is limited only by the capabilities of the support ship and the weather conditions on the surface. As a result, these vehicles can remain submerged at great depths for days and even weeks while they survey large areas of ocean floor. Furthermore, unmanned submersibles demand only a small support ship and crew, making them relatively inexpensive to operate.

Last September's historic discovery of the wreck of the ocean liner *Titanic* was made possible with the aid of an unmanned craft, the Argo, which was tethered to a ship on the surface by a 13,000-foot umbilical cable that sent back data from its TV cameras and sonar scanners. Scientists sitting in the comfort and safety of the support ship's control room were treated to breathtaking views of the *Titanic* in its final resting place, without having to endure the crushing pressures, perpetual darkness, and near-freezing temperatures of the ocean floor.

Submersibles constitute a growing share of the $800 million market for undersea services and offshore support equipment. Leading applications include inspection and maintenance of offshore drilling rigs, undersea pipelines, and telephone and power cables. Submersibles are also used by the world's navies for a variety of military missions, and by marine scientists to study the geology and biology of the deep ocean.

While some submersibles, like the Argo, are towed platforms with no independent propulsion system, most are remotely operated vehicles (ROVs), which use electric propellers to maneuver through the water. The umbilical cable that connects the ROV to the surface support ship, typically about two-thirds of an inch in diameter, carries electric power and commands down from the ship and transmits video signals and sensor data up for shipboard processing and display. The umbilical carries several channels of analog and digital information in both directions simultaneously. "ROVs are replacing human divers in a great number of subsea tasks,"

says Don Lamkin, marketing director of Perry Offshore (Riviera Beach, Fla.), a major manufacturer of the vehicles. "People who used to work at depths of 900 feet are now on the surface doing the same job with a submersible."

Among the first ROVs was a U.S. Navy craft called CURV (cable-controlled underwater recovery vehicle), which caught the world's attention in 1966 when it recovered a hydrogen bomb that had been lost a half mile under the Mediterranean after two military planes collided. The Navy continued to develop ROVs for military missions. Commercial ROVs came on the scene in the 1970s, largely in response to major oil and gas discoveries in the North Sea; capable and reliable ROVs presented an economically attractive alternative to human divers and manned subs for work on subsea drilling equipment in these cold, deep waters.

Over 700 ROVs have become operational since 1975, more than half of them for civilian applications, according to Frank Busby, an Arlington, Va., consultant specializing in undersea technology. The three main U.S. manufacturers are Ametek Straza (El Cajon, Cal.), Hydro Products (San Diego), and Perry Offshore. Leading foreign companies include International Submarine Engineering (Port Moody, B.C., Canada), Société ECA (Meudon, France), Slingsby Engineering (Kirkby Moorside, York, England), Osel Group (Great Yarmouth, England), Sutec (Linköping, Sweden), and Gaymarine (Trezano sul Naviglio, Italy).

The recent oil glut has reduced economic incentives for new offshore oil production and thus slowed the growth of the ROV industry, but many believe that this is a temporary setback. "It's a much tougher market today than it was a few years ago," says Gary Stenovec, manager of special projects at Ametek Straza. "But we still feel that there's plenty of room for future expansion."

Until recently, most commercial ROVs were limited to inspection tasks. They served as roving underwater "eyeballs"—maneuverable vehicles carrying lights, TV cameras, and other visual sensors to spot flaws in offshore structures such as drilling rigs, wellheads, and pipelines in waters too hazardous for human divers. All offshore structures in the North Sea, for example, are required by law to undergo visual inspection at regular intervals.

Advances in manipulator technology and remote-control systems have led to a new class of ROVs that do more than just look around. According to Busby, 70% of ROVs are now equipped with at least one manipulator arm, ranging from a simple grabber to a pair of highly sophisticated robot arms. Such ROVs can perform delicate repair and assembly tasks, including recovery of lost gear, sample collection, and attachment or removal of components or recovery cables.

Hydro Products' RCV-150, for example, is designed for offshore drilling support to a depth of 2000 feet, with options to 5000 feet. The unit is furnished with searchlights, a TV camera, sonar, and a manipulator arm that can be fitted with a gripper hand or saw wheel. The arm can hold 60 pounds when extended to its full length of three feet. A shipboard control panel with a joystick enables the operator to "fly" the ROV underwater much like piloting an airplane. A sister product, the RCV-225G, consists of a free-swimming, observation-only ROV and a separate manipulator that can lift 120 pounds when fully extended (eight feet). Separate video cameras mounted on the inspection ROV, the protective cage from which it's launched, and the manipulator arm provide complementary views of the undersea work site.

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ROVs capable of heavy-duty undersea work are much larger than observation-only vessels and thus require more buoyancy and thrust. To maximize durability and minimize weight, ROV manufacturers are increasingly using composite materials and highly buoyant chemical foams.

The Scorpio, introduced by Ametek Straza in 1977, is considered by many to be the first truly reliable and efficient underwater work system. It is used for offshore oil-drilling support, such as assisting the installation of the "Christmas tree" unit that regulates oil flow out of the well. To date, 57 Scorpios have been sold, and an improved version, known as Super Scorpio, was introduced in 1985.

Operating to a depth of 3000 feet, the Scorpios have two manipulators: a five-function arm controlled by a single joystick or set of toggle switches, and a seven-function arm controlled by a "master/slave" system. The slave arm is mounted on the ROV, and a smaller replica—the master—is located in the support ship's control room. The operator simply moves the master arm to the desired position; a computer measures the new coordinates and transmits the corresponding control signals to the slave arm on the ROV. Both of the ROV's manipulators are electrohydraulic and require a flow of 25–27 gallons of hydraulic fluid per minute. According to Ametek Straza's Stenovec, the chief difference between Super Scorpio and its predecessor is power: 60 horsepower versus 25, giving it greater thrust and maneuverability.

Perry Offshore offers a very large, 100-horsepower ROV called Triton that can work at depths of 5000 feet. Marketing director Lamkin likens the unit (which costs about $1 million) to a tractor-trailer rig in that it can carry a number of different "work packages" consisting of one or two manipulators and a set of specialized tools. One such package, for example, is designed to clean marine growth off undersea drilling platforms. "The ROV is prewired so that you can change work packages in the field as requirements dictate," says Lamkin.

The communications industry also uses sophisticated ROVs to repair undersea telephone cables, which are occasionally damaged by fishing vessels trawling on the continental shelf. In the late 1970s, Bell Telephone Laboratories (Holmdel, N.J.) developed a large ROV work system called the Submersible Craft for Assisting Repair and Burial (SCARAB), with funding from Transpacific Communications (a subsidiary of AT&T Long Lines) and an international consortium of telecommunications companies. Two SCARABs, built by Ametek Straza and costing $6 million, went into operation in 1980.

Capable of operating to a depth of 6000 feet, SCARAB is the deepest-diving commercial ROV in operation today. It is the size of a small truck, weighs 6300 pounds, and has two large five-function manipulator arms that make it look like a giant mechanical lobster. The ROV's aluminum frame contains flotation tanks, seven electric thrusters that can propel it in any direction, a 35-horsepower electric motor and hydraulic system for actuating its robot arms, two zoom TV cameras, a fixed-focal-length TV camera, a 35-mm still camera, and floodlights. SCARAB also has sensors for depth, temperature, and pressure, a locator system that constantly indicates its position relative to the surface ship, and four magnetometers that find a buried telephone cable by detecting the 25-hertz current passing through it.

CHRISTOPHER SPRINGMAN

After being lowered from a specially outfitted cable-laying ship, SCARAB propels itself along the seabed on a pair of skids, its headlights beaming and TV cameras operating. Three crewmembers aboard the cable ship direct and monitor the ROV's every move.

After homing in on a section of faulty cable, SCARAB goes to work. The robot first uses a tool called a jetter, which shoots out powerful streams of water to excavate a deep trench in the seabed and expose the buried cable. After this 5–10-minute operation, the ROV slices through the cable with a rotary saw. The next step calls for human assistance: The ship's crew lowers a coiled rope, which SCARAB attaches to one of the cut ends of the cable with a gripper hook. The ROV then releases its hold on the hook, and the rope is winched to the surface with the cable attached. This procedure is repeated for the other cable end. After the cable has been repaired aboard ship and lowered back to the seabed, SCARAB cuts away the rope and uses the jetter to rebury the cable.

An operator aboard a prospecting ship (top) surveys seabed manganese nodules with the video-camera "eyes" of an unmanned submersible thousands of feet below the surface.

The French Epaulard (bottom) is an untethered ROV that surveys along a preprogrammed path, taking still photos and slow-scan video images (at eight-second intervals) before returning to the surface. Since 1979, Epaulard has made more than 200 dives.

SCARAB is not restricted to communications tasks. Last July the ROV made headlines when it recovered the "black box," or flight data recorder, from the wreck of an Air India 747 that crashed off the coast of Ireland with 329 people aboard. During the salvage, SCARAB combed a 1- by 10-mile swath of ocean floor where the wreckage was thought to be. The ROV homed in on acoustic signals from the black box, and its TV camera caught sight of it at a depth of 6700 feet. After SCARAB had grasped the black box in its mechanical claw, controllers on the surface ship winched the ROV to the surface. SCARAB is now salvaging portions of the wreckage.

Other applications of ROVs include assessing fish populations and photographing areas of the ocean inaccessible

Cutting the umbilical

To liberate a submersible from the tether requires considerable on-board computing power. The goal is a vehicle that can be thrown overboard, do its job, and return to the surface, all without human intervention. The University of New Hampshire's EAVE-East is probably the most advanced autonomous submersible in the civilian world, with five microprocessors that plan the vehicle's activity in accordance with sensed data on altitude, depth, obstacles, and power consumption.

Consider what happens when the EAVE (for Experimental Autonomous Vehicle) encounters a slope on the ocean floor—or, for now, the bottom of Lake Winnipesaukee, where the vehicle is being tested. Three sensors (the upward- and downward-looking sonar and the pressure gauge) simultaneously register change. One microprocessor takes raw data from the sensors and produces an objective statement: "The bottom is rising." Another processor analyzes this situation in relation to the vehicle's speed and ability to manuever, and generates a subjective conclusion: "The bottom is rising too fast"—that is, the vehicle is in danger of grounding.

At the same time, another potential problem is spotted: the EAVE is using too much energy in one thruster, and risks running out of fuel before completing the mission. A microprocessor decides that the craft must change course, and consults a rough map of the local environment stored in memory. The solution: Survey the intended area by moving back and forth along the grade rather than up and down it, thereby saving energy and avoiding the risk of grounding. The on-board computers issue signals to the vehicle's thrusters to follow this new path.

In tests planned for this summer, the EAVE will require about 100 seconds to recognize a gentle slope and figure out how best to compensate for it while accomplishing its mission, according to Richard Blidberg, associate director of New Hampshire's Marine Systems Engineering Lab. Simpler operations—such as detecting and avoiding an obstacle—should take only about 3 seconds, he says. Next year the EAVE will undergo further trials in the New Hampshire lake; the year after, in the ocean. ***—Peter Britton***

UNIVERSITY OF NEW HAMPSHIRE

Researchers ready EAVE-East for testing in Lake Winnipesaukee, N.H. The autonomous vehicle uses a microprocessor-based navigation system that allows it to maneuver around obstacles.

by other means. The U.S. Navy employs ROVs for a variety of missions such as mapping the topography of the ocean floor, examining sunken craft, retrieving torpedoes and other objects, installing listening devices on the seabed for antisubmarine warfare, and disposing of enemy mines. For example, the Naval Ocean Systems Center (NOSC) in San Diego recently developed a tethered ROV that can classify and neutralize mines located by sonar. The Navy will deploy this system on its next class of minesweepers.

Extensive research is under way to improve the dexterity and precision of ROV manipulators and to make them more amenable to remote control. Because the ocean environment is so unpredictable, undersea robotics is much more challenging than designing systems for, say, the factory assembly line. Objects may be randomly oriented, encrusted with marine life, or buried in silt, and strong ocean currents can disturb the position of the manipulator.

In the short run, the basic task best suited to an underwater manipulator will be assembly—grasping and putting objects in place—for offshore oil applications. A longer-term goal is to develop light, nimble manipulators capable of picking up a delicate biological or geological specimen without damaging it. Advanced ROV manipulators might also take apart undersea machinery for maintenance or repair.

Other components of the ROV are also being improved. For instance, the coaxial cable now used for communication with the surface ship has been replaced by fiber optics in a few advanced ROVs. Fiber optic cable increases roughly 100-fold the amount of data that can be transmitted simultaneously, says Robert McKee, director of business development at Hydro Products. Moreover, the thin, lightweight optical cable creates less drag as the ROV moves through the water, and it allows a less elaborate handling system on the surface; winches, for example, can be smaller and cheaper.

Another approach to advanced ROV work systems is to improve the man/machine interface, making it easier for the human operator sitting in the support ship to exert fine control over the manipulator arm of an ROV located thousands of feet below. In most current ROV systems, the operator watches a TV monitor showing the ROV's field of view, and manipulates a joystick whose positions correspond to the motions of the manipulator. More advanced control systems provide tactile feedback, so the forces acting on the manipulator can be felt as joystick resistance. NOSC has also developed a viewing system that enables an operator wearing a special helmet to aim and pan the ROV's TV camera with head movements, leaving hands free to work the manipulator.

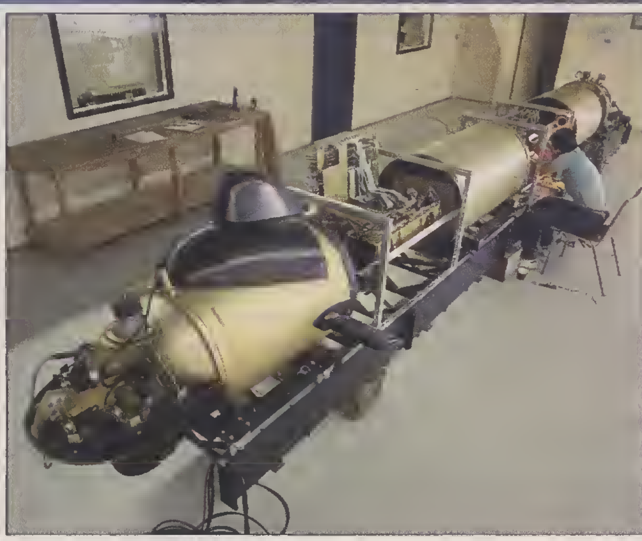
Such efforts at simulating the presence of the operator at the undersea work site are not very convincing, though, because visual observation is limited to a flat TV image that shows only a small segment of the total scene, contains no depth information, and is often distorted by the camera's wide-angle optics. Moreover, controlling the manipulator demands such skill and concentration that fatigue sets in after a few hours.

An ROV that could perform a number of simple but important functions automatically would ease the operator's task tremendously. Researchers at Heriot-Watt University (Edinburgh, Scotland) have developed a microprocessor-based, closed-loop control system that automatically maintains the ROV's heading and depth at a specified setting, using data from an acoustic navigation system. The operator can trans-

mit a revised setting at any time.

A far more ambitious ROV control system is under development in the Man-Machine Systems Laboratory at MIT. Thomas B. Sheridan, professor of mechanical engineering and applied psychology, is leading work on a supervisory system that will integrate a large computer into the control loop. A human operator will give the computer high-level commands, such as ordering the ROV to move its manipulator to a certain location. The computer will then translate this command into a detailed set of control instructions, signaling the mechanical actuators in the robot arm exactly how and when to move, and reacting automatically to feedback data from sensors monitoring the position of the arm.

Supervisory control should also make it possible to coordinate the movements of the manipulators with those of the vehicle as a whole. For



PETER BRITTON

Hydro Products' RCV-225G (top) consists of a free-swimming vehicle containing a video camera, and a separate eight-foot manipulator arm. The remotely controlled system can remain submerged for days on end to inspect and maintain undersea drilling rigs.

The Autonomous Remote Controlled Submersible, or ARCS (bottom), shown during assembly at International Submarine Engineering, is an untethered vehicle designed for under-ice geological surveys in the Canadian Arctic. ARCS will embark on its first commercial mission in May.

example, when an ROV is working in mid-water, rather than on the bottom, the only way a manipulator can develop enough torque to lift an object is to counterbalance the applied force with the vehicle's thrusters. This procedure demands a highly skilled operator and some degree of force feedback. Ideally, the supervisory control system would coordinate the manipulator and vehicle motions automatically.

Sheridan also suggests that supervisory control might be applied to ROV observation tasks. The supervisory system might integrate and interpret the raw data transmitted from the ROV to the ship's control room, converting it into easily comprehensible graphic displays. Or the operator might tell the computer to keep the vehicle's TV camera trained on a particular fish as it swims about, a task requiring sophisticated pattern-recognition capability.

Supervisory control sys-

BUSINESS OUTLOOK

Smoother sailing ahead for submersibles

Over the past ten years, unmanned submersibles have shown versatility in commercial, military, and scientific tasks. The petroleum and communications industries use them for placing, inspecting, and repairing offshore installations such as cables, pipelines, wellheads, and drilling rigs, while their principal military application is to neutralize mines. Fees charged by underwater support contractors for the use of submersibles amounted to $120 million in 1985—15% of the total $800 million market for underwater services and equipment—according to Petrodata Consulting, a British firm. Within two years submersibles are expected to represent 18% ($183 million) of a $1 billion total market.

Most submersibles are remotely operated vehicles (ROVs)—self-propelled devices able to maneuver through the water in all directions while connected by cable to a surface ship. Some 750 of these machines have been deployed since the mid-1970s, in addition to 100 other specialized devices, according to Frank Busby, an offshore-industry consultant in Arlington, Va. Initially, most ROVs could only perform observation tasks, but the largest segment of the current market consists of machines that can also use manipulators for work functions.

In the U.S., the major manufacturers of civilian ROVs are Perry Offshore (Riviera Beach, Fla.), Ametek Straza (El Cajon, Cal.), and Hydro Products (San Diego).

"An unmanned, remotely operated vehicle is usually less expensive and always safer to use than divers. Although lacking a human's dexterity and feel, the machine has more strength and endurance, and can be effectively deployed at greater depths."

Jon Newman, VP
Business Development
Perry Offshore

Leading foreign companies include England's Offshore Systems Engineering and Slingsby Engineering, Canada's International Submarine Engineering, Sweden's Scandinavian Underwater Technology, and Italy's Gaymarine. The market for military craft is dominated by a single French company, Sociêtê ECA.

Component equipment for ROVs is produced by vehicle manufacturers and a large group of independent suppliers. For example, Craft Ocean Systems (Kansas City, Kans.) offers a dextrous "slave" manipulator that duplicates the motion of a master arm in the control system aboard the surface ship. Underwater video cameras and photographic equipment are made by Photosea Systems (San Diego). Birns Oceanographics (Los Angeles) sells lighting components, and Mesotech Systems (Vancouver, B.C.) has introduced color-imaging sonar.

Because two-thirds of the ROVs in use are tied to offshore oil operations, demand for submersibles is largely influenced by oil companies and their contractors, such as Oceaneering International and its deep-water subsidiary, Ocean Systems Engineering (Houston). "Sales of general-purpose machines, costing around $400,000, have dropped in recent years as contractors learned to utilize their ROVs more effectively and as improved training resulted in fewer ROVs being lost," says G. Allen Brooks, VP of Offshore Data Services (Houston).

ROV revenues have also been affected by the price of oil, which has declined from $34 per barrel in 1981 to the mid-$20s at present. "With their cash flow down and future price ranges uncertain, oil companies prefer not to take a chance on initiating exploratory drilling and development in waters deeper than 1000 feet," says Leonard LeBlanc, engineering editor at *Offshore* (Houston), a trade journal. These are the areas where ROVs are the most cost-effective and are sometimes the only alternative. But it is less expensive to work close to shore than in deeper waters, he says, and easier to project costs and profits. LeBlanc observes that offshore operations have been picking up in shallow portions of the Gulf of Mexico, among other areas, and that ROVs are complementing the activities of human divers in these projects.

Moreover, several other trends indicate brighter prospects for ROVs. "It used to be assumed that platforms would be maintained by manned divers," says Offshore Data's Brooks. "Now, however, the majority of platforms are being designed to accommodate ROV manipulators; for example, valves are faced outward from the platform so that machines can approach them more easily."

"Any extension in the use of submersibles will require stereo viewing systems to improve depth perception in murky waters, more sensitive force feedback from manipulators, and the availability of compatible subsea equipment."

F. Richard Frisbie
General Manager
Ocean Systems Engineering

JERRY JONES

In addition, ROV sales are increasing at both the high and low ends of the market. Contractors are showing interest in large vehicles to which specialized, modular work packages can be attached; although such systems may cost $1 million and up, they can take the place of several machines whose capabilities overlap.

At the other extreme, $30,000 observation-only ROVs are beginning to appear in inland lakes and rivers. According to Frank Busby, these submersibles, weighing only 40–60 pounds, can be deployed from a ship or land base. They are used to search for stolen goods and missing persons, and to inspect piers, dams, and electrical cables. "This year will indicate how well such ROVs are being accepted," he says. "In time, a new onshore market could open up for high-volume production of cheap submersibles." ***—Dennis Livingston***

tems are still a long way from commercialization, but when they arrive they will make a big splash. Says Sheridan, "The entire ROV community is working toward a situation in which a large computer on the support ship performs all the number-crunching activities—such as interpreting high-level commands, running simulations, and generating displays—while the lower-level commands are executed by microprocessors on the ROV itself."

The ultimate goal of ROV technology is to develop autonomous vehicles that do not need the power/control tether. As the depth of a tethered ROV increases and its operating range is extended, the drag created by the tether causes difficulty in maneuvering and raises the power requirements. As a result, the vehicle thrusters must become larger, and so must the vehicle as a whole. More energy is also required for cable winching and tending, giving rise to massive, complex, and costly shipboard handling facilities. The tether poses other problems as well; a number of ROVs have been lost at sea when the tether got snagged or was severed by the support ship's propeller.

Freed from its umbilical, an ROV could work within the hull of a sunken ship without risk of entanglement, or search and survey under ice. A number of untethered ROVs are already in the experimental stage. Probably none will reach the market for another five years, however, because removing power and control cables creates a number of daunting technical challenges. Power is no longer available from the surface, for example, so the ROV must carry storage batteries. Since this requirement reduces the capacity for heavy work, untethered vehicles will probably be restricted to inspection tasks.

Removing the control cable also means that either the mission must be preprogrammed into the ROV's software, or remote-control signals must somehow be transmitted through the ocean. Researchers are experimenting with a number of communication modes, including radio and blue-green lasers, but so far only sound waves have been made to propagate reliably for long distances through seawater. An "acoustic tether" has some serious drawbacks, however. For example, because sonic energy dissipates rapidly with distance, the power requirement of an acoustic tether grows geometrically as the ROV moves away from the surface ship.

Another crucial drawback of acoustic communications is its slow rate of information transfer—under 10,000 bits per second, or a tiny fraction of the 66 million bits per second needed to transmit a conventional TV picture. Thus, experimental untethered ROVs use slow-scan video systems that transmit a few still frames at a time rather than a continuous moving picture. The full data are recorded on a videocassette for later viewing, and the slow-scan images serve mainly to reassure the operator that the vehicle is still under control. Transmitting real-time video signals through the ocean from an untethered ROV will require new signal-compression techniques to reduce the amount of data without sacrificing the quality of the video images. Such systems will in turn require that the ROV carry powerful microprocessors to do the necessary number crunching.

A third problem with an acoustic tether is sonic interference. Any interface—such as the seafloor, a boundary between water of different temperatures (thermocline), or a large object—will scatter sound waves, creating echoes that degrade the signal. Interference is particularly severe if the ROV is working within a complex underwater structure.

Moreover, there is a time delay caused by the relatively slow speed of sound—about 5000 feet per second through water. In contrast, electromagnetic impulses travel down a cable at close to the speed of light. Thus for an untethered ROV at a depth of 1½ miles, it takes over three seconds from the time a command is sent down acoustically from the ship for a response to be verified. This delay complicates remote-control operation, making it necessary to interpolate the ROV's probable path between transmissions.

The ultimate goal is to develop autonomous underwater vehicles that do not need a tether from a surface ship to provide power and control signals.

Despite these problems, several experimental ROVs that use acoustic tethers are already being field-tested. The Advanced Unmanned Search System (AUSS), developed by NOSC, is designed for search and survey missions to depths of nearly 20,000 feet; it employs an advanced acoustic communications system that has transmitted acceptable slow-scan TV pictures. In addition, researchers at Heriot-Watt have developed an untethered vehicle called Rover, which is deployed from a larger tethered ROV. An acoustic communications link carries video signals and vehicle-control data between Rover and the larger ROV.

Several industrial, academic, and military laboratories are already working on the next step: an autonomous underwater vehicle (AUV) that requires no command signals from the surface. Most such systems are limited to automatic control on simple programmed or target-seeking trajectories. For example, the French Epaulard, built by Société ECA and operated by International Underwater Contractors (City Island, N.Y.), can dive to the ocean floor, take still photos, and return on its own to the surface. And NOSC is developing an experimental AUV called the Free Swimming Vehicle, which is designed to follow a set of preprogrammed tracks.

The first commercial untethered ROV is the Autonomous Remote Controlled Submersible (ARCS), which was developed by International Submarine Engineering (ISE) and is currently undergoing sea trials. Designed as an under-ice survey vehicle for use in the Canadian Arctic, ARCS is powered by nickel-cadmium batteries and has an on-board microprocessor programmed with the mission to be performed.

ARCS can dive to 1200 feet and travel for 23 hours at five knots, returning to the site of its launching for recovery. It can survey five square kilometers of ocean bottom while a digital echo sounder measures bottom depth and profiles geological structures beneath the seafloor. Sensors monitor the ROV's depth and the water's salinity and specific gravity. Data are transmitted acoustically to the surface.

ARCS will embark on its first commercial mission in May, for the Bedford Institute of Oceanography (Halifax, Nova Scotia) and Canadian Hydrographic Survey (Edmonton, Alberta). The operation may reveal opportunities for offshore oil drilling in the Canadian Arctic. The vehicle will be marketed at $800,000, according to ISE spokesman Michel Gervais.

A truly "intelligent" AUV will have to combine a number of advanced technologies. Although microprocessors already pack an enormous amount of computing power, software lags far behind, and the key problem will be to put the available machine intelligence to work efficiently. Research on AUVs is being funded by the Defense Advanced Research Projects Agency, whose new Strategic Computing Program envisions the development of fully autonomous military vehicles for use on land, in the air, and underwater.

Argo's odyssey: exploring the seabed

Woods Hole's Ballard stands on deck of the research ship *Knorr* with submersibles used for ocean-floor surveying—the Angus (foreground) and the more sophisticated Argo (which played a key role in the discovery of the *Titanic*).

The *Titantic*-hunting Argo brought public attention to deep-water unmanned submersibles. Under development since 1979 by Robert D. Ballard and colleagues at the Woods Hole Oceanographic Institution (WHOI—Woods Hole, Mass.), the Argo is about the size of a compact car and weighs more than 4000 pounds. It is equipped with TV cameras and lamps, as well as a side-scan sonar system that makes high-resolution maps of the seafloor, mainly for scientific exploration. The vehicle was designed so that various subsystems are discrete modules, each controlled by its own microprocessor. This architecture facilitates maintenance and makes it easy to add or subtract sensors.

Unlike free-swimming remotely operated vehicles (ROVs), the Argo is pulled behind a research ship at the end of a miles-long umbilical cable that supplies power and a communications link. Towed at about one knot, the Argo "flies" over the ocean floor at an altitude of 150–200 feet. Suspended about 100 feet below is an imaging pod containing up to five video cameras, which provide overlapping views to yield a composite picture of a 300- by 1500-foot patch of ocean floor.

To record scenes in the blackness of the deep ocean, the Argo carries TV cameras that are 200 times as light-sensitive as the fastest photographic film in comon use. Intense strobe lamps permit the cameras to see farther than 300 feet. The strobes flash once every five seconds, creating video snapshots. The video signals travel up the umbilical to the mother ship, where a digital image processor enhances edges and contrast for easier interpretation.

At present, the Argo must be positioned over the sea bottom by carefully maneuvering the surface ship. Because of the slow and complex dynamics of a towed vehicle at great depth, however, this task is very demanding for the human operator, and its precision is limited. Woods Hole researchers are currently working on a closed-loop control system that will keep the Argo stationary over one spot on the seafloor or moving along a prespecified track.

Such improvements may bring new uses for Argo-like submersibles. Indeed, WHOI's Ballard has formed a company—Deep Ocean Search and Survey (Woods Hole)—to develop deep-diving unmanned submersibles for commercial applications.

To complement Argo's wide-area surveys, WHOI is developing a small ROV, called the Jason, to perform close-up inspection and manipulation. The Jason will be deployed from the Argo and controlled with the aid of the larger craft's video cameras. Jason's job description is deliberately being kept loose; the vehicle is designed to perform "highly unstructured tasks in difficult and poorly understood environments," says program head Dana R. Yoerger.

While the Argo is maintained about 100 feet above the seafloor with the aid of sonar beacons, the Jason will maneuver to the work site at the end of a fiber optic tether. Using stereo color TV and two robot arms, the Jason will shoot close-up video images and still photographs, collect samples, and deploy and recover instruments on the seafloor. The human operators aboard the surface ship will be able to see through the Jason's stereo eyes while simultaneously observing the ROV at work on the seafloor from the Argo's high vantage point.

Development of the Argo/Jason system is expected to reach completion in 1988, at a total cost of $2.8 million.

—Jonathan B. Tucker

WOODS HOLE OCEANOGRAPHIC INSTITUTE

The most advanced AUV described publicly is the Experimental Autonomous Vehicle East (EAVE-East), developed at the University of New Hampshire (Durham). This vehicle is designed to inspect pipelines and the interior of offshore structures. It is controlled entirely by microprocessors programmed with a description of its assigned mission, a database of facts that might affect the mission, and a set of decision-making rules. In response to sensor inputs, the control system examines and weighs alternative courses of action and then issues the appropriate commands to the vehicle (see "Cutting the umbilical," p. 20).

The capabilities of AUVs are still quite limited, and many problems remain to be solved. To ensure reliability, the craft must be able to handle a wide range of operational conditions, tactical alternatives, and system failures. Moreover, the navigational system must cope with noise and unreliable data while calculating the vehicle's position to an accuracy of inches within complex offshore structures. Visual pattern-recognition systems may eventually allow navigation by landmark recognition, which is less prone to noise than present sonar and gyroscope-based systems, but that technology is still far from perfected.

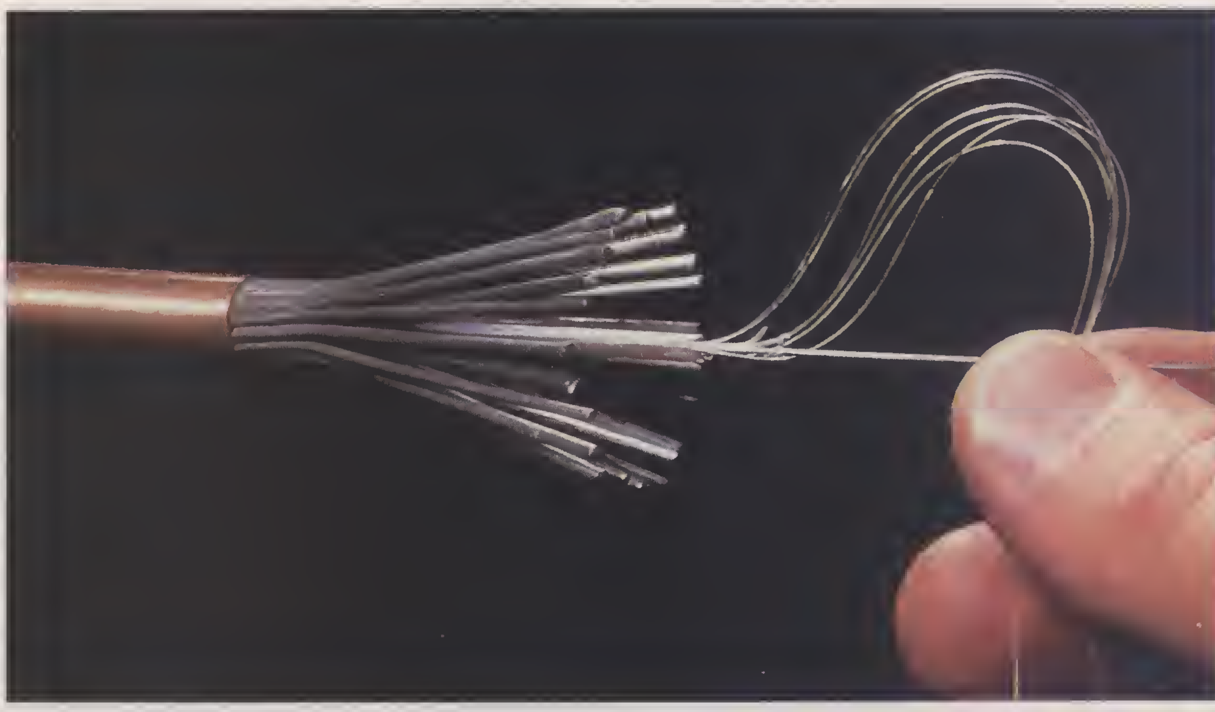
Today's commercial ROVs cannot dive below 7000 feet, and in fact usually venture no deeper than 3000 feet. Yet the deep-ocean floor is 20,000 feet down. Oil and gas exploration will be moving into increasing depths over the next ten years, and deep-diving ROVs will be needed. Such vehicles will also be useful in mining manganese, nickel, cobalt, copper, and other valuable minerals that have been found on or beneath the seabed (HIGH TECHNOLOGY, Jan. 1984, p. 26). Unmanned submersibles should provide a relatively inexpensive way to survey large areas of the ocean floor, optimizing mining efforts by identifying prime resource sites.

Finally, deep-diving ROVs promise to open a vast new frontier for scientific exploration. Indeed, although men have walked on the moon, human eyes have seen less than a tenth of 1 percent of the ocean floor. □

Jonathan B. Tucker is a former senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES**, *p. 69.*

NETWORKING WITH LIGHT



Increasingly, local and long-haul communications firms are turning to fiber optics

by Martin Pyykkonen

Fiber optics, an enterprise that was still experimental as recently as the late 1970s, is now becoming the medium of choice for sending digital transmissions in communications networks. Its technical and economic advantages are being firmly established in intercity and metropolitan applications in the U.S. and other industrialized countries. And undersea applications, such as the TAT-8 project that will connect the U.S. to England and France, are expected to show that fiber optics can be more effective than satellite systems for high-capacity point-to-point transmission of both voice and data.

Fiber optics is also moving beyond the high-capacity, long-distance realm into local-area networking applications. The cost of connections that link computers and terminals to fiber networks has been dropping—an important factor for LANs, which have many devices linked to the network in a concentrated area. Also, individual companies that would once have been hard pressed to exploit the large bandwidth of a fiber LAN are requiring increasing network capacity as computers and data-intensive applications such as computer-aided design proliferate.

Behind the multiplying applications of fiber optics are several technological advances, such as the advent of "single-mode" fibers that can carry signals of optimal wavelength for long-distance propagation. Many of these applications require transmission speeds of at least 400 megabits per second (Mbps), which single-mode fiber can easily accommodate. Within three or four years, in fact, such fiber optic networks will likely be able to handle greater than 1000 Mbps (1 gigabit per second, or Gbps) over distances of 30 or more miles without the need for amplification. No less important that the single-mode fiber cable itself is the growing availability of inexpensive and reliable light sources and sensitive detectors, made possible by new materials.

Fiber optic infrastructure. Major fiber optic networks are currently being installed by each of the seven regional Bell Telephone companies, numerous independent telephone companies, and long-distance common carriers such as AT&T Com-

munications, MCI, and GTE Sprint. Some specialized long-haul network providers are also installing fiber capacity, including a seven-company consortium called NTN (National Telecommunications Network), headquartered in Washington, D.C. These projects could result in nearly 10 billion circuit-miles of installed fiber optics by 1990, mostly in urban networks in major U.S. metropolitan areas (a single cable may support thousands of circuits). Already there is substantial operating capacity in such cities as Boston, New York, Chicago, Los Angeles, and San Francisco.

So much fiber optic capacity is being installed in the U.S. that some observers claim there will be a "bandwidth glut" within three years. In fact, the nationwide plans of Fibertrak (Reston, Va.) have been placed on hold because of insufficient demand and inadequate financing. But such developments appear to be the exception rather than the rule, and the construction plans of many public and private carriers are proceeding full speed ahead. AT&T Communications (Bedminster, N.J.) is modernizing its older analog and digital copper long-haul network with fiber optic systems that can transmit at over 400 Mbps on a single fiber (a rate capable of supporting approximately 6000 voice circuits). United Telecom (Kansas City, Mo.) plans to build a 23,000-mile nationwide fiber optic network to connect all 48 contiguous states. United will build part of its own network and lease existing capacity in areas such as the northeastern U.S., where Lightnet (New Haven, Conn.), a joint venture between the CSX railroad and Southern New England Telephone, is already operating high-capacity fiber optics.

The involvement of CSX points to an important development in the industry. Unlike AT&T, many other long-haul carriers lack the rights-of-way to install miles of fiber cables; this situation explains in part why many AT&T competitors have relied on satellites for long-distance transmissions and microwaves for local traffic. But lately, companies with sizable real estate assets and valuable rights-of-way have begun to play a major role in the telecommunications industry. Railroads, electric power companies, and oil and gas pipeline companies are all leasing their rights-of-way to long-haul carriers for fiber optic networks.

Several carriers are already enjoying prosperous times merely by supplying such long-distance pathways. For example, LDX Net, one of the seven NTN companies, operates private-line nonswitched fiber optic facilities in Texas, Louisiana, and the Midwest. Rather than operating as a full-service long-haul carrier with dedicated switching equipment, the company simply delivers bundled voice and data packets either to the local telephone company or directly to large end users. LDX Net uses 400-Mbps fiber optic systems to provide connections between cities, such as Dallas and Houston, and then distributes traffic locally to the telephone company on lower-speed, 135-Mbps facilities (equivalent to about 2000 circuits).

By simply dumping bundled packets at the doorstep of the phone company or corporate user—rather than performing the end-to-end message routing itself—LDX Net can make a profit even if its network isn't filled to capacity. "With a total embedded plant cost of less than $1 per circuit-mile, we can break even at only 10–20% of capacity," says Don Hutchins, executive VP.

Metropolitan networks. The benefits of fiber optics are also being realized in metropolitan-area applications both public and private. Prompted by the speed and range of fiber optics, local telephone companies are replacing copper transmission facilities in high-density business districts and selectively in residential ("subscriber loop") locations. But one of the main reasons for rapid deployment is the continuing threat of network "bypass," by which large users circumvent public network facilities and establish their own communications systems. Because fiber optic systems can discourage bypass—by providing a readily available "highway" for high-speed voice, data, and video—local telephone companies are beginning to modernize their switching and transmission facilities.

For example, Illinois Bell has placed a 144-fiber cable (capable of carrying nearly half a million standard voice or data circuits) through the downtown Chicago area. Coupled with optical electronics conveniently linked to individual buildings in the city, the network—called Novalink—offers high-speed information transport to corporate users. Novalink is nonswitched, however, so users must arrange for separate switching service.

Other metropolitan applications provide full switching and routing, made possible by remote switching facilities that can be placed close to the user. In this way, individual lines can be consolidated into a higher-capacity link—such as a fiber optic cable—for transmission to the central office's main switching node. (Otherwise, each telephone and data terminal would require a separate line traveling all the way to the local phone company's central office.) The AT&T Network Systems 5ESS central office switch, for instance, has a remote switch module that can be located up to two miles from the main switch. "This fiber optic link is currently based on simple LED devices and multimode fiber," says L. Charles Brown, manager of sales planning at the AT&T Network Systems manufacturing plant (Oklahoma City). "But by mid-1986, long-wavelength lasers will be used with single-mode fiber to extend the maximum distance between the main switch and remote switch module to about 25 miles."

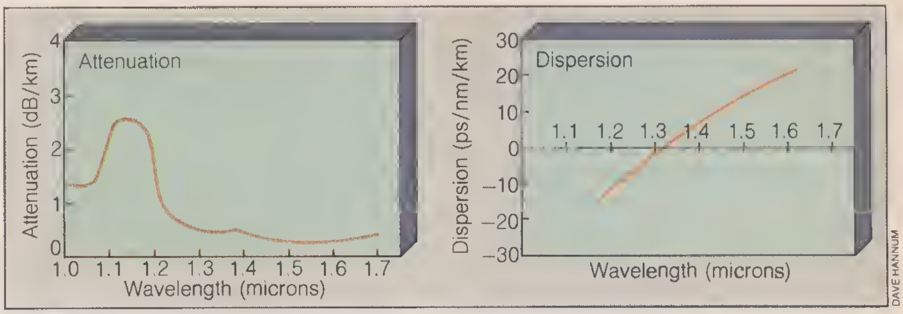
Metropolitan applications are not confined to the public networks. Even though fiber optics presumably helps to keep bypass at bay, its availability in wide-area private networks often prompts large users to bypass public facilities anyway. Whether public or private, networks based on fiber optics are increasingly being chosen because they offer better control of communications costs (although they are not al-

OVAK ARSLANIAN

ways the least expensive alternative) and superior performance.

It is these criteria that have helped justify the development of several U.S. "teleports," such as the New York Teleport, a joint development of the Port Authority of New York–New Jersey, Merrill Lynch Telecommunications, and Western Union. This teleport is a wideband communications service designed to meet the enormous information needs of the area. Over 100 miles of optical fiber throughout the city provides direct connections between offices in Manhattan and a satellite communications center in Staten Island.

While the adoption of fiber optics in urban networks is driven by the business demand for readily available high-capacity transmission, the economics of replacing the subscriber-loop portion of the public networks with fiber optics can be more difficult to justify. No one denies that fiber optics can offer equivalent capacity with much less cable than copper systems, but this advantage can be offset by telephone companies' enormous capital investment in their existing copper networks. In the subscriber loop, traffic volume is relatively low and sites are dispersed, so the advantages of embedded copper carrier facilities must be weighed closely against the benefits of replacing them. There's no set solution to this equation: In California, Pacific Bell is upgrading its copper facilities rather than moving to fiber optics immediately, while at Bell South (Atlanta)—parent company of South-



Devising a fiber that minimizes both attenuation and dispersion is difficult because each shows a minimum loss at a different wavelength.

Individual glass fibers can be wound into a variety of cable configurations. A typical cable has about 72 fibers, but high-traffic applications may require 144-count cable.

ern Bell and South Central Bell—the emphasis is on placing single-mode fiber throughout the subscriber loop as soon as possible to deliver voice, data, and video services to homes.

Local-area networks. Only recently has fiber optics been seriously considered for local-area networks (LANs), which are contained within a single building or, in the case of so-called campus networks, a tight cluster of buildings. In campus networks there is a need to connect departments with a high-capacity transmission capability for voice, data, and video traffic. Such networks have been installed at Stanford and the University of Pittsburgh, and will soon be installed among 19 buildings at the Rockefeller Center complex in New York.

The principal obstacle to more general use, however, has been material cost. Although installation and maintenance costs are generally comparable to those of competitive media such as baseband or broadband coaxial cable, components such as optical sources, detectors, connectors, and multiplexers boost the cost of fiber optic LANs considerably. The user gets impressive performance and reliability, but the cost can be hard to justify.

"We have put fiber optic LANs in some buildings for customers who have been willing to pay the additional price, with a view toward future communications needs," says Ralph K. Ungermann, president of Ungermann-Bass (Santa Clara, Cal.), a supplier of both coaxial-cable and fiber optic local-area networks. Still, notes Ungermann,

Spinning strands of glass

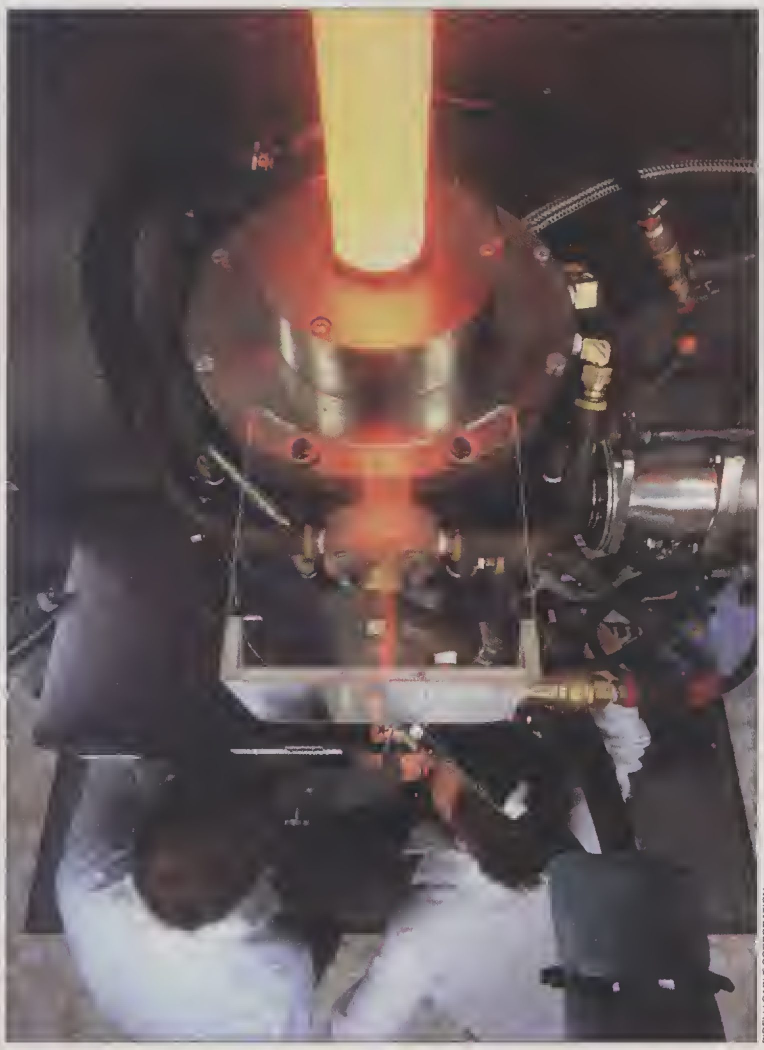
Optical fibers require extremely precise manufacturing techniques. Because a single finished fiber is less than half as thick as a human hair, and because mere traces of impurities can cause severe signal attenuation, the entire fabrication process must be finely controlled to permit only minuscule variations in the output.

There are two main types of fiber fabrication: outside vapor deposition (OVD) and modified chemical vapor deposition (MCVD). The latter is an "inside" method of fabrication, in that it deposits the core material—typically in the initial form of metal halide vapors—on the inside of a cylindrical silica-substrate tube. The vapors deposited inside the tube (which has a ½-inch center hole and a ¾-inch outer diameter) eventually form the core of the fiber, and the tube itself forms the cladding. Once the chemical deposition is complete, the tube is heated to a molten state and stretched by a computer-controlled fiber-drawing tower into its final form. A two-foot tube can yield more than 30 miles of optical fiber. "MCVD is the preferred method of fabication for both multimode and single-mode fiber because of its consistency in a high-volume production environment," says Don Ames, a department chief at AT&T Network Systems (Atlanta).

Proponents of OVD disagree. With this process, the metal halide vapors react in an open environment, producing a very fine-grained white soot. The soot is blown against a long ceramic rod that rotates about its axis. Once the proper diameter is achieved, the "blank" is cooled and separated from the rod. The porous blank then passes through an oven in which cleansing gases remove any impurities; the blank is then heated and stretched through the standard drawing process.

One advantage of OVD is that it permits the oven purification step, says David Charlton, marketing manager at Corning Glass Works (Corning, N.Y.), who notes that the MCVD process occurs in a closed environment in which any impurities will be "frozen." "For example, we normally end up with around 10 parts per billion of water—a contaminant—and MCVD blanks normally run 100 to 500 ppb," he says. "The higher water content results in a lot more attenuation at certain wavelengths."

A third fabrication process—vapor axial deposition (VAD)—is a variation on OVD. Rather than depositing the vapor soot on the side of a ceramic rod, however, the soot is built up on the end of the rod. This process is used by some Japanese firms and could, in theory, permit a manufacturer to fabricate any length of fiber. But Charlton claims that it's more difficult to achieve a consistently round fiber cross section with VAD than with OVD. Because OVD fibers have very concentric cores, they experience much lower losses when two fibers are spliced together, he says.



PIRELLI CABLE CORPORATION

A molten "preform" is drawn into a hair-thin fiber.

most of the fiber links his company has installed are connections between buildings—connections that are specially requested for reasons such as immunity to lightning strikes or increased message security. "We're still a few years away from fiber being the most important LAN medium," he says. "Coaxial is still here for a while."

The next two years, however, should bring significant improvement in cost-effectiveness. Optical transceivers, which combine the source and detection function in a single unit, will be available for less than $100 each, whereas an optical source alone can today cost as much as $300–$400. Also, optical connectors that provide individual user access to the LAN will become readily available as mass-producible designs replace existing products that require precise optical alignment of a bare fiber and the connector. A number of companies are active in developing and marketing fiber optic components, including AT&T Technologies (Morristown, N.J.), Northern Telecom (Nashville, Tenn.), Siecor Electro-Optics Products (Research Triangle Park, N.C.), General Optronics (Edison, N.J.), Lasertron (Burlington, Mass.), Amphenol (Danbury, Conn.), Kaptron (Palo Alto, Cal.), and Deutsch (Hemet, Cal.). Japan's NEC and Fujitsu are also major players.

In some LAN applications, particularly new office and factory buildings where there is no existing wiring, the optical fiber medium is already becoming established. AT&T Information Systems, for example, offers a modular Premises Distribution System that combines twisted-pair and fiber optic circuits in a single package, with proportions to be chosen according to the user's need for speed and capacity. IBM offers a similar option for the cabling systems that form a key element of its local-area network strategy.

Fiber optics provides other telecommunications advantages that often count more in LANs than speed and capacity: Cabled fiber is narrow and lightweight, immune to electrical noise and interference, and capable of secure transmission. These advantages are thought to make fiber optics particularly well suited for networking the "factory of the future."

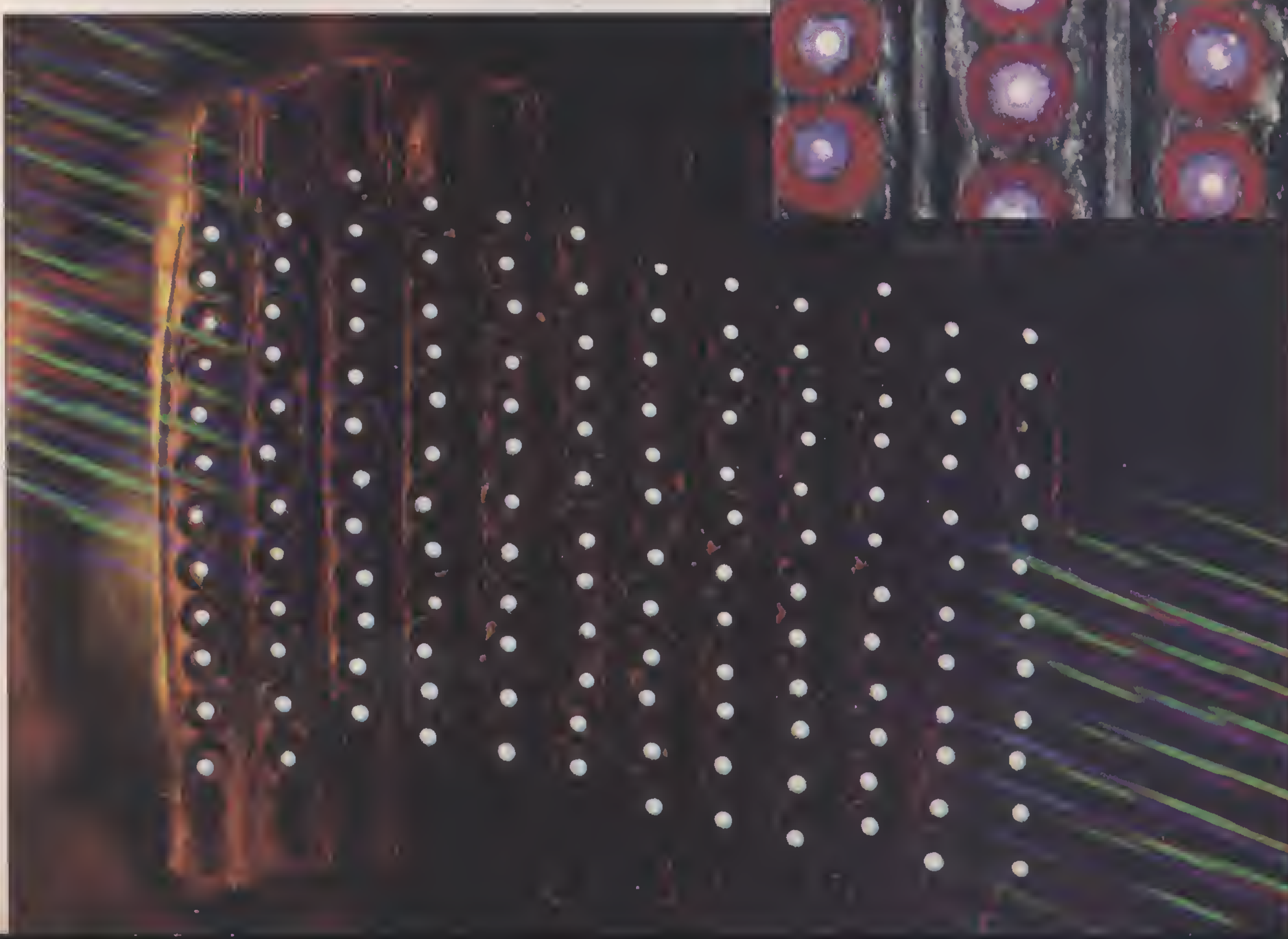
Optical technology. All fiber optic applications, from long-haul networks to LANs, are being made possible by advances in the fibers themselves, in optical devices that send and detect the signal, and in the connectors that provide access to the network. Systems can now operate at nearly 1 Gbps over a distance of about 25 miles without any signal amplification; the closest terrestrial competition is the copper wire, which is limited to less than 100 Mbps at a maximum distance of only a few miles.

An optical fiber is a hair-thin strand of glass composed of silicon and other materials such as germanium. It consists of a light-transmitting core and a layer of cladding that keeps the light from straying. Fibers are bundled together to produce cables of varying capacity. An average cable contains about 72 fibers; the highest-count cable available bundles 144 fibers.

The earliest fiber optic systems were multimode, meaning that they carried several lightwaves down the fiber si-

PHILIP HARRINGTON

A magnified cross section of a 144-fiber cable at Bell Labs shows the core, cladding, and sheath layers of each fiber.



PHILIP HARRINGTON

BUSINESS OUTLOOK

Fiber optics: not just for the long haul

Fiber optics has quickly become the preferred medium for transmitting voice, data, and video in the U.S.—especially over long distances—because more information can be sent with greater speed and security over thin strands of glass than by conventional cable. Within populous metropolitan areas, for example, six-inch copper cables can be replaced with half-inch fiber cables that carry the same amount of information. U.S. revenues for fiber and component suppliers were about $500 million in 1985—representing half of the world total—and should climb to $1.5 billion by 1989, according to John Kessler, president of Kessler Marketing Intelligence (Newport, R.I.), a fiber optics market research firm.

"We are starting to deploy a fiber network that will extend into the home. Using one terminal that can handle voice, video, and data, the consumer could control energy management, receive pay-per-view TV, and query a database for information, with greater ease and efficiency than ever before."

Kathy Kaplan
Staff Manager
Network Planning
Southern Bell

Telecommunications applications account for more than 60% of the fiber market. Glass fibers for this segment are supplied by such companies as AT&T Technologies (Berkeley Heights, N.J.), ITT (New York), Corning Glass Works (Corning, N.Y.), Spectran (Sturbridge, Mass.), and Japan's Sumitomo. Another group of firms competes for the sale of components such as lasers, connectors, and multiplexers, which direct and control signals transmitted through fiber cables. These companies include RCA (New York), Lasertron (Burlington, Mass.), Lytel (Somerville, N.J.), General Optronics (Edison, N.J.), M/A Com (Burlington, Mass.), Rockwell International (Pittsburgh), Telco Systems (Menlo Park, Cal.), Northern Telecom (Mississauga, Ont.), and NEC, Hitachi, and Fujitsu of Japan.

Fiber is being used for long-distance and local telephone transmission. Long-haul firms, such as AT&T Communications (New York), MCI Communications (Washington, D.C.), GTE Sprint (Stamford, Conn.), and United Telecommunications (Kansas City, Mo.), have been the largest single users of fiber optics over the past decade.

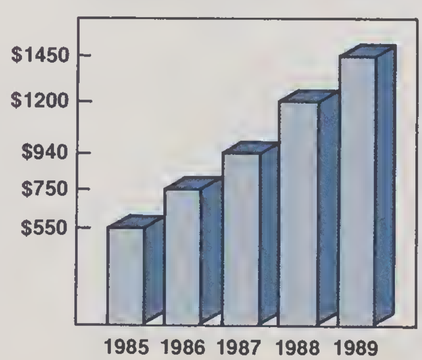
"Deregulation of the telephone industry encouraged competition in the long-haul sector, which stimulated the fiber optics market," says Kessler. "A host of new coalitions emerged, in which telecommunications firms teamed with pipeline, railroad, and utility firms to provide right-of-way and high-performance transmission." Lightnet, for instance, is a joint venture of railroad company CSX (Richmond, Va.) and Southern New England Telephone (New Haven, Conn.).

Plummeting cost is another factor behind the popularity of fiber: In 1977, a meter of fiber cost $3.50; last year, it cost 25¢. The price of 24-gauge copper wire, on the other hand, has risen from 1.5¢ to about 2¢ over the same period. But even though fiber is still more expensive than copper, Kessler expects that its superior cost-effectiveness will prompt telephone companies to increase the total amount of installed fiber cable from 32,000 today to 100,000 miles by 1989.

Some industry observers worry that this growth is too rapid—that it will result in a temporary glut in capacity. But Ronald Contrado, director of corporate development at Homisco (Revere, Mass.), a supplier of telephone information systems to hotels, maintains that "the downward pressure on transmission costs will stimulate telephone companies and value-added networks to fill the pipeline with videotex and other services."

While the telecommunications industry has accounted for most of the fiber business, it may not be the dominant player for long. "Non-telephone uses are growing so fast that this arena will share roughly half the revenues of the fiber optic market by 1989," says T. K. Lakshmanan, president of TK Technologies (Matawan, N.J.), a market research firm.

Estimated U.S. fiber optic market in millions of dollars



Source: Kessler Marketing Intelligence

For example, use of fiber by government and the military should grow by 40% annually over the next five years. The size and weight advantages of fiber cables and the secure nature of fiber transmissions—fiber's optical pulses are virtually untappable—make this technology especially appealing for use in space vehicles and military communications equipment. Companies supplying this market include Spectran and Artel Communications (Worcester, Mass.).

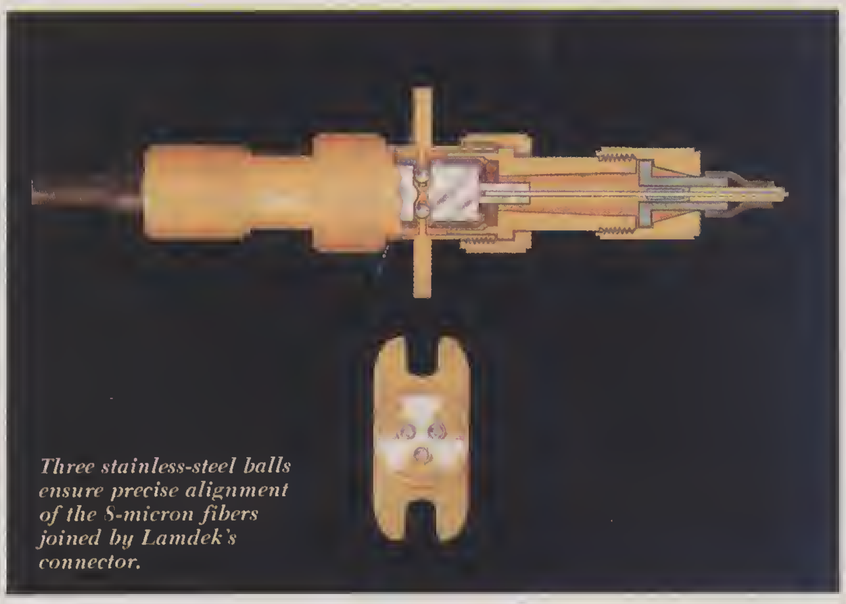
The local-area network (LAN) market for fiber is achieving growth rates above 50% a year, according to Lakshmanan, and is being propelled by businesses' needs for reliable linkages between computers and peripherals. Fiber LANs are also being used to interconnect all communications within a single building or a cluster of buildings. For example, Manhattan's World Trade Center is being wired with fiber because rooftop antennas that collect microwave and video transmissions could interfere with computer terminals connected by coaxial cable.

Fiber LANs are supplied by such firms as Fibronics International (Hyannis, Mass.), Proteon (Natick, Mass.), and Ungermann-Bass (Santa Clara, Cal.). Large computer companies are also supplying fiber optic systems for use in data processing and some manufacturing operations. For instance, 20% of the 3500 Ethernet LANs installed by DEC (Maynard, Mass.) incorporate fiber optics.

A new market for fiber involves sensors and transducers that collect and supply information on such parameters as pressure, temperature, and light, for manufacturing operations and consumer products. Originally developed by the military, these fiber-wired—and therefore lightweight and reliable—devices are now being incorporated into a variety of industrial processes by such firms as Gould, Hitachi, and Ford Aerospace. "This market is now only about $30 million annually," says Lakshmanan, "but it could triple by 1989 because of the potentially wide range of commercial applications." ***—Theresa Engstrom***

NANCY KRIEBEL

multaneously. But multimode cables were plagued by excessive signal attenuation (reduced optical intensity) and dispersion (spreading of the optical pulse). Single-mode fiber, which transmits a single direct beam light, has since been developed. It achieves higher performance, in part because the core diameter has been reduced from 50 microns (standard for multimode fiber) to about 8–10 microns. The smaller diameter permits single-mode fiber to send a concentrated light beam farther than multimode, because the light strikes the core/cladding boundry at a much smaller angle, resulting in less attenuation and dispersion.



Three stainless-steel balls ensure precise alignment of the 8-micron fibers joined by Lamdek's connector.

An optical fiber cable by itself is nothing more than a passive medium through which light flows. Most of the work, then, is performed by transmitting and receiving devices at each end. Digital information is sent by a laser or LED optical source device and then detected by an APD (avalanche photodiode) or PIN-FET (p-intrinsic-n field-effect transistor). An LED/APD combination offers modest performance with the benefit of high reliability and low cost, while the high-performance laser/PIN-FET combination costs more and is less reliable. (In a source/detector combination, performance refers to the maximum output of the source and the minimum optical sensitivity required to detect the signal. Performance, along with fiber attenuation, splice losses, temperature variations, and other design parameters, determinines maximum speed and distance.)

Many of the materials and manufacturing methods for optical devices have been derived from semiconductor technology. Pure silicon and germanium were used in some of the earliest discrete optical sources and detectors. Today's integrated optical circuits are fabricated from lithium niobate, gallium arsenide, and indium phosphide.

Fabrication techniques for lithium niobate are about 5–7 years ahead of gallium arsenide, its closest competition. "But it has the disadvantage of being useful only as an optical waveguide [grooves that guide light on the chip], not as a material for integrating the active device elements [source/detector] and the waveguide on the same substrate," says Rod Alferness, head of the Photonics Circuits Research department at Bell Labs. Gallium arsenide can be used to manufacture integrated optical circuits that incorporate the waveguide and active elements on a single substrate. It offers high speed, but is suitable only for operation below optimal wavelengths (where the attenuation and dispersion are minimized).

Indium phosphide has emerged as the material of choice for long-wavelength devices. Like gallium arsenide, it can also be used for integrating the optical waveguide and active devices. Still, indium phosphide waveguides have a drawback: Their attenuation is currently more than 25 times that of lithium niobate, according to Alferness. But he expects that as manufacturers gain more experience developing and producing devices, the loss will fall to a level of less than 1 decibel/centimeter. Such a loss will be on a par with that of lithium niobate, and should precipitate a shift to indium phosphide.

As the technological advances in fiber optic cable and devices move from the laboratory to production and installation, they will cause new communications services and products to emerge, according to Jon Zilber, manager of marketing research at Kessler Marketing Intelligence (Newport, R.I.), a research firm specializing in fiber optics. Because of the enormous capacity fiber optics will provide, he says, carriers will be forced to come up with new applications in order to fill their networks.

A similar response is predicted for hardware producers. "The long-term ramifications of fiber optics are enormous," says Zilber. "Once this huge-bandwith channel is available, the computer companies will come up with new devices to utilize it, and there will be a new emphasis on video applications such as picture phones. In particular, we're seeing a major trend toward computer graphics for such applications as CAD/CAM, and fiber optic networks will provide the necessary infrastructure." □

LAN vendor Ungermann says the cost of connectors still limits fiber optics' role in buildings.

Martin Pyykkonen is a senior consultant in the telecommunications division of Arthur D. Little.

MONOCLONAL ANTIBODIES: PROMISES FULFILLED

Proteins for diagnosing disease are already on the market. The next step: treatment.

Eleven years ago, two researchers in Cambridge, England, devised a simple yet elegant method for producing antibodies—immune system proteins that bind to and help destroy foreign molecules and organisms. Whereas previous approaches resulted in mixtures consisting of hundreds of millions of different antibody configurations, the British technique featured an intriguing new twist for immunologists: It let them select just one antibody of special interest—comparable to plucking a single grain of gold from a bucket of sand—and then reproduce it in large amounts.

There were two important outcomes of the Cambridge work:

- Immunologists were handed one of the most powerful and versatile tools yet devised for understanding the workings of the immune system.
- Because the scientists did not patent their discoveries, commercial rights to the technology passed from its British proprietors to an "open-market" status. As a result, the obscure immunological research tool—now known as monoclonal antibodies (MAbs)—is today worth $130 million in annual sales and stands to become a $2-billion-plus worldwide business by 1990, according to England's Celltech, a top-ranked MAb company.

One important reason for such numbers is MAbs' growing role in finding and treating disease *in vivo* (in the body); the proteins have thus far been limited almost exclusively to *in vitro* (outside the body) diagnosis. But several *in vivo* MAb-based detection methods for cancer and heart disease are expected to move soon from clinical trials to commercialization. And within five to ten years, MAbs linked to chemicals and radioisotopes are almost sure to become standard alternatives (in at least some cases) to conventional cancer treatments such as surgery and chemotherapy.

The mood among most MAb companies is a mixture of heady optimism and sober acknowledgement of the obstacles to profitability. For example, the MAb community—mostly small, pioneering companies—is threatened by competition from pharmaceutical giants. "Abbott isn't going to sit back and watch its business eaten away by 20 smaller companies," says Yves Fouron, vice-president of business development at BioResponse (Hayward, Cal.), a leading MAb producer. Thus, intense competition both from within the MAb community and from without is forcing MAb companies to carve out unique proprietary niches for themselves.

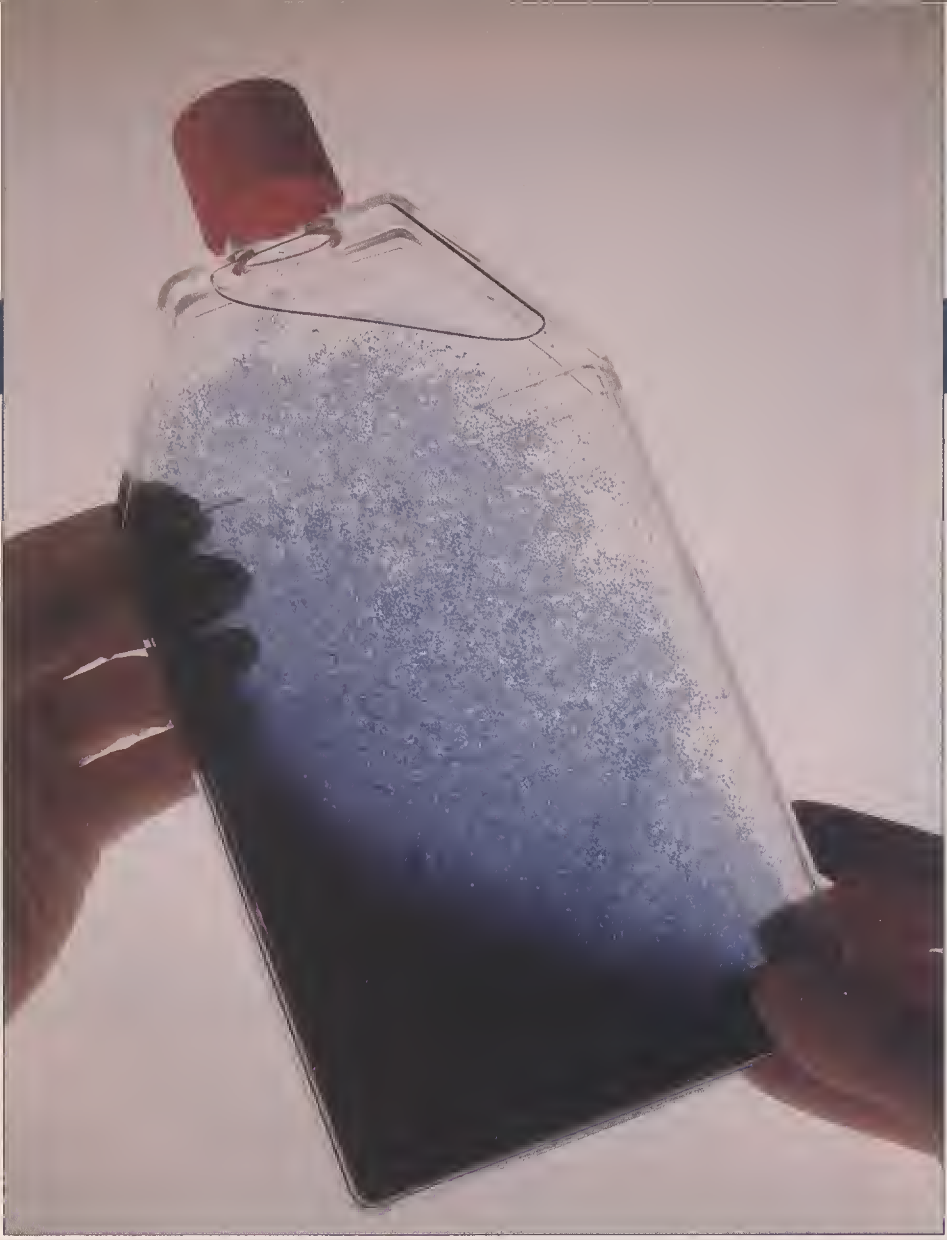
Another hurdle is that the large-scale MAb production required for market expansion is still beset by serious technical problems. And in the area of *in vivo* cancer detection and treatment, researchers are often stymied by the notorious unpredictability of malignant cells, as well as by the problems of specificity (the tendency of a MAb to bind to one and only one target).

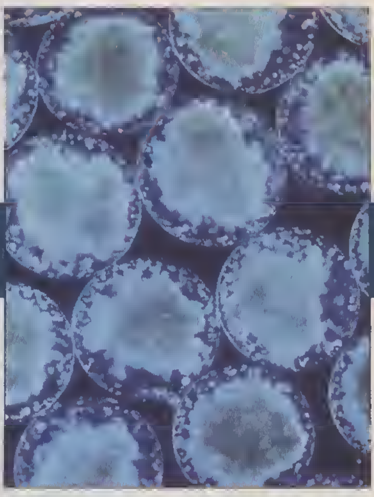
Despite these and other obstacles, there's a growing recognition of monoclonals' staying power, as illustrated by two recent acquisitions: MAb pioneer Hybritech (San Diego) was purchased by pharmaceutical giant and prospective competitor Eli Lilly, and Genetic Systems (Seattle) was acquired soon afterward by Bristol-Myers. While the moves could be interpreted as "preemptive strikes" by the buyers, most observers saw them instead as timely votes of confidence in the long-term viability of the young technology. "With a combined purchase price of $600 million, those buys finally put a real value on this industry," says Nigel L. Webb, president of Damon Biotech (Needham Heights, Mass.).

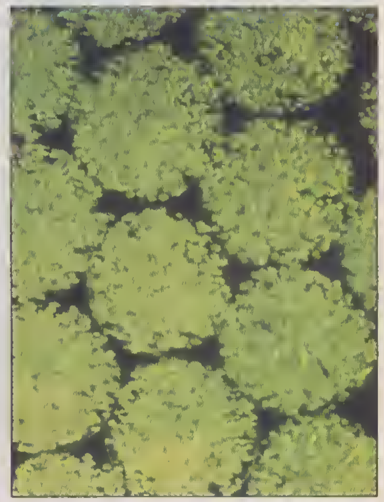
Just as significant, says Webb, is the growing perception that the MAb industry has far outpaced its once glittering sister technology, recombinant DNA, which uses gene manipulation to create new pharmaceutical products such as interferon and human growth hormone. (No such manipulation is normally used in MAb production.) In fact, only two or three genetically engineered products are now on the market, versus more than 100 MAb-based diagnostic kits.

One important reason that MAbs are enjoying wider commercialization is that they travel a smoother regulatory road. The FDA typically takes up to seven years to fully review the clinical data for a new drug. But MAbs are expected to move through the approval maze in only about a third that time, because of the growing body of evidence about their safety and efficacy—evidence that in some cases may be extend-

by H. Garrett DeYoung







A flask at Damon Biotech (left) teems with tiny capsules containing antibody-secreting hybridomas. Top photo shows the high internal densities. At Karyon (bottom), hybridomas grow in gel without capsules.

ed across antibody families. "The body is already accustomed to carrying large amounts of antibody," says Webb. "That's not true for the large amounts of interferon that will probably be used for therapy."

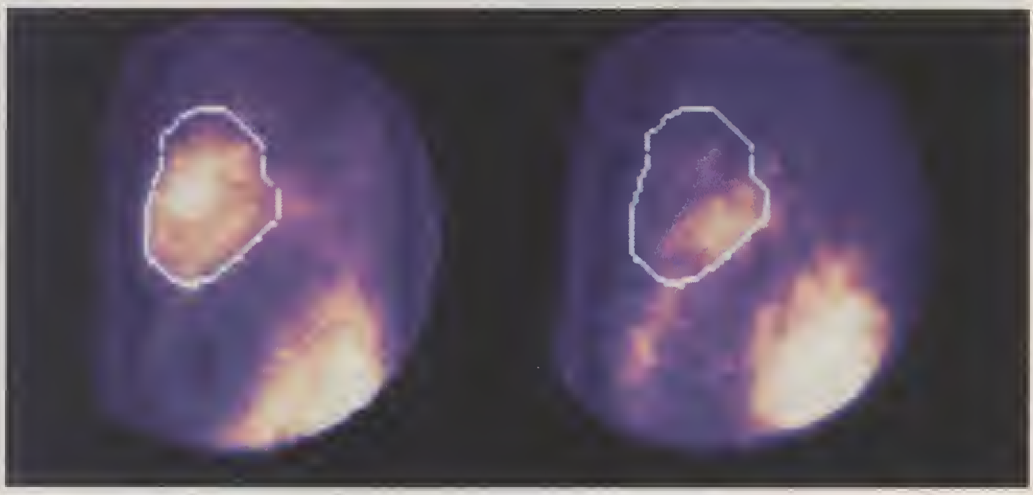
Protective proteins. Antibodies (also called immunoglobulins) are natural mammalian proteins that "recognize" and bind to one or a very few molecular targets. White blood cells called B-lymphocytes produce hundreds of millions of these antibodies as a defense against foreign invaders, or antigens. (While *antigen* often denotes a foreign organism or cell, it also refers to any of hundreds or thousands of distinctive, individual substructures on the invader's surface.) Each antibody carries on its binding site a precise sequence of amino acids, determined by the genetics of the parent B-lymphocyte; this chemical sequence forms a geometrically unique site for recognizing, and attaching to, a corresponding antigen. The antibody's point of attachment is precisely defined by a sequence of only 7–11 amino acids. Changing even a single amino acid could result in an altogether different antibody–antigen reaction.

In 1975, Cesar Milstein and Georges Köhler in Cambridge, England, learned how to produce large amounts of just one antibody that recognized just one antigen—an effort that earned them a 1984 Nobel Prize. By and large, their procedure is still used virtually unchanged. The researchers first injected the antigen of interest (in this case, red blood cells from a sheep) into a mouse; the lymphocytes soon began to produce large amounts of antibodies, some of them directed specifically against the sheep cells. The normally short-lived lymphocytes were then isolated and fused with cancer cells called myelomas. The new hybrid cells (or hybridomas) exhibited the genetic characteristics of both parent cells; they produced the same antibody as the lymphocyte and were as durable as the cancer cell. As a result, the hybridomas became veritable antibody factories.

Two features distinguished the antibodies produced by these hybridomas: They were all specific to (that is, directed against) the original sheep-cell antigen, and they were uniform because they were all derived from a single B-lymphocyte. Such genetically identical cells are called clones, so the antibodies they produce are called monoclonal.

Until recently, MAb commercialization has been limited almost exclusively to *in vitro* diagnostic kits, first for hospitals and physicians' offices but increasingly for the do-it-yourself market

H. Garrett DeYoung is a senior editor of HIGH TECHNOLOGY. *His book on monoclonal antibodies,* The Cell Builders, *will be published by Doubleday this summer.*



Abnormal cells are imaged with isotope-carrying monoclonals that bind only to the cells. Top: Antigen molecules on the surface of cancer cells appear as bright green spots. Bottom: Two images of antibodies bound to dead cardiac tissue (inside white circles). Bright spot at lower right of each image is the liver.

(HIGH TECHNOLOGY, Nov. 1985, p. 73). The disposable, easy-to-use kits typically consist of strips of paper impregnated with MAbs specific to the target molecule—blood enzymes, for example, or a hormone associated with pregnancy. Other MAb kits test for infection, some forms of cancer, and blood levels of therapeutic drugs.

Product purification is another common MAb application. One example is Damon Biotech's long-term contract for purifying the alpha-interferon produced in genetically engineered bacteria by Hoffmann-La Roche (Nutley, N.J.). Once an antibody is made against the interferon, the parent lymphocyte is fused to make a hybridoma that is then "grown" at Damon. The resultant pure antibodies are mixed with the interferon (which contains a variety of foreign proteins, bacterial debris, and other contaminants) and bind tightly to the target molecules, permitting the other components to be separated out.

Coming of age. The Hybritech and Genetic Systems acquisitions are just one indication that the MAb industry is growing up and shaking down. Another is the specialization taking place among most of the premiere companies and many of the start-ups as well. Says Damon's Webb, "Most companies establish themselves and gain experience through contract work"—that is, producing antibodies from hybridomas created elsewhere, as in the Damon Biotech/Hoffmann-La Roche collaboration. But companies now realize that "babysitting" other researchers' cells isn't enough. They must develop proprietary antibodies and related services to impress prospective clients and wary investors who, says one observer, "still roll their eyes when you mention biotechnology."

Several companies hope to accomplish these aims through patented MAb-based imaging and/or treatment methods based on immunoconjugates (two-part molecules consisting of a MAb and a chemically linked, or conjugated, radioisotope or drug). In late 1984, for example, MAb producer Centocor (Malvern, Pa.) announced its proprietary antibody, called Myoscint, for detecting and measuring heart damage—a MAb application that Centocor believes could generate $120 million in worldwide sales by 1988.

As heart muscle dies (during a heart attack, for example) it releases small amounts of the protein myosin at the damaged site. Working with researchers at Massachusetts General Hospital, Centocor grew the antimyosin MAb, then conjugated it to the short-lived radioisotope indium-111. In the patient, the MAb binds to the cardiac myosin as a special camera images the indium's location and concentration. By arming cardiologists with such quantitative information, the method could be an important new tool for treating damaged tissue and preventing further attacks.

Such tools could also play an important role in the diagnosis and treatment of cancer. Centocor, for example—a pioneer of *in vitro* MAb diagnostics—now has several imaging conjugates in clinical evaluation, including one for colorectal cancer. Other firms developing MAb imaging systems include Hybritech, Genetic Systems (Seattle), NeoRx (Seattle), and Cetus (Emeryville, Cal.).

The reason for the interest is that many malignancies, even very small ones, can now be imaged *in vivo* with MAbs grown against a specific type of cancer cell. "There have been several cases in which this technique has spotted tumors that were missed with a CT scan," says Hybritech's Joanne Martinis, vice-president of cell culture. "Unfortunately there have also been a large number of false positives and negatives," probably because the MAbs were not specific enough. Martinis notes that

DANIEL FORT

Monoclonals linked to radioisotopes have found some tumors that escaped detection by CT scans, says Hybritech's Martinis.

Hybritech has developed a proprietary MAb that detects a pigmented form of cancer called melanoma in 70% of melanoma patients screened.

Lethal cargoes. It is the promising new cancer therapies that most capture the imagination of the medical profession. While no one expects that MAbs will completely displace conventional treatments, they stand to become the best hope for many forms of cancer, especially some now treated through chemotherapy. Most of these drugs work by attacking fast-growing cells such as cancer cells (as well as normal cells of the digestive tract and other systems). One reason chemotherapy is sometimes ineffective is that some cancers proliferate relatively slowly; several of these cancers are now considered prime targets for therapy with monoclonals.

One approach is to use MAbs by themselves—that is, unconjugated—on the premise that the immune system is a natural first-line defense against cancer. "If patients' own antibodies were functioning properly, they probably wouldn't have cancer," says Martinis.

Unconjugated MAbs are under study at several sites for treating B-cell lymphoma and other human lymphatic cancers. In some cancers of this type, malignant cells carry a group of immunologlobulin chains (called the idiotype) that represents an antigen for the MAb. Large amounts of anti-idiotype antibody are prepared, then injected into the patient, where they bind to the malignant cells. As in the normal immune response, the binding signals other immune system components—enzymes, for example, and large white cells called macrophages—to attack the "labeled" antigen. The results of these studies have thus far been mixed, but it appears that at least one B-cell lymphoma patient who did not respond to conventional treatment has been cured by anti-idiotype therapy.

A more promising approach is to utilize MAbs' specificity as a means of delivering a lethal toxin only to malignant cells, thus sparing healthy cells from damage. In such methods, a cancer-killing chemical is conjugated to the antibody. More commonly, the payload is a radioisotope. "We know more about the physiological effects of radioactivity," says Martinis, "and it's easier to kill neighboring cells with radioisotopes. With an attached drug, you really have to bind to every malignant cell."

In some cases, she adds, it may be possible to press a MAb into dual service by linking it first to an imaging isotope to locate the target, then to a toxin to destroy it. Another alternative is to manage the disease by destroying, say, 90% of the cancer cells by means of immunoconjugates, then to inject the patient with a combination of immune system boosters—interferon, for example, or the natural chemicals called interleukins—to mop up the rest. (Interleukin therapy received a major vote of confidence late last year, when the National Cancer Institute reported that intransigent tumors in 11 of 25 cancer patients apparently responded to treatment with a form of interleukin called IL-2. The physicians in the study cautioned that the results are still preliminary, however, and that extensive follow-up work remains.)

The first clinical trial of immunoconjugates against lung cancer, conducted by the Research Institute of Scripps Clinic (La Jolla, Cal.), started on a small group of patients in mid-1985. The trial (which will be conducted throughout this year) will evaluate the effectiveness of antibodies alone and antibodies conjugated to the widely used anticancer drug methotrexate. Meanwhile, another MAb company—Cytogen (Princeton, N.J.)—has recently announced a joint venture with the Italian pharma-

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BUSINESS OUTLOOK

Monoclonal antibodies enter new markets

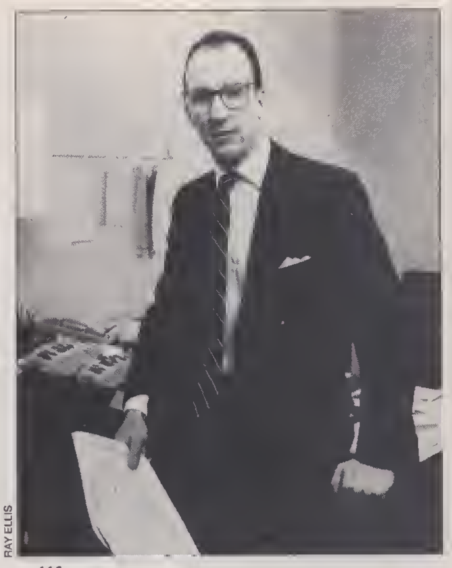
Monoclonal antibodies (MAbs)—protein molecules able to recognize and bind to specific organic substances—are a growing part of the market for *in vitro* (outside the body) diagnostic products. U.S. sales for MAb-based diagnostics were estimated at $133 million for 1985 (20% of the $665 million overall market for *in vitro* diagnostics), and are expected to jump to $620 million by 1987. By then, MAb sales will represent 62% of a $1 billion diagnostic market, according to analyst Peter Drake of Kidder, Peabody (New York).

Over 100 Mab-based *in vitro* tests are now used to check for pregnancy, diagnose infectious diseases, monitor the efficacy of therapeutic drugs, facilitate tissue-matching for organ transplants, and detect tumor cells.

MAb products are now offered by several of the established leaders in the diagnostic products field, including Abbott Laboratories (North Chicago), Becton Dickinson (Paramus, N.J.), Johnson & Johnson (Raritan, N.J.), Syntex (Palo Alto, Cal.), and Roche Diagnostics (Nutley, N.J.). A second group of companies, founded expressly to develop MAb products, includes market leaders Hybritech (San Diego) and Centocor (Malvern, Pa.), as well as Genetic Systems (Seattle), Damon Biotech (Needham Heights, Mass.), BioResponse (Hayward, Cal.), Karyon Technologies (Norwood, Mass.), and Monoclonal Antibodies (Mountain View, Cal.). Hybritech and Genetic Systems were recently acquired by Eli Lilly and Bristol-Myers, respectively.

"We're using MAb technology to develop simple tests that can be carried out in nonhospital settings," says Gregory Sessler, vice-president for finance at Monoclonal Antibodies. For example, several MAb-based tests for pregnancy and for predicting the fertile period of a woman's reproductive cycle are now available. Pregnancy tests for use in homes and physicians' offices currently represent a $100 million U.S. market, while fertility testing, a time-consuming and costly process before MAbs, could create a market of more than $100 million by 1989, according to Sessler.

Tests to identify bacteria and viruses are rapidly gaining acceptance. Revenues from MAb-based virus tests alone should multiply from $5 million in 1984 to about $90 million in 1987, says Drake of Kidder, Peabody. This surge is largely due to a massive federally sponsored blood-screening program initiated in 1985 to track the virus responsible for AIDS. While growth from this application will not continue as rapidly, says Drake, sales of *in vitro* diagnostics for other infectious diseases should assure continued growth in the foreseeable future.


RAY ELLIS

"Large pharmaceutical companies are gaining access to monoclonal techniques by acquiring smaller biotech firms that pioneered the field. At the same time, they are providing new products developed by these firms with more marketing clout."

Peter Drake
Analyst
Kidder, Peabody

In addition to human medical applications, MAbs may be applied in several other arenas over the next few years. For example, the food industry may soon begin using MAb-based tests for detecting bacterial contamination. This market could grow to $35 million by 1988, says Drake. MAbs will also be used increasingly in industrial-scale purification of fine chemicals, a market that could reach $20 million by 1987. In agriculture, Molecular Genetics (Minnetonka, Minn.), has marketed a monoclonal product for relieving scours, a diarrheal disease that afflicts newborn calves.

Over the next decade, MAb-based technology will increasingly be used for *in vivo* (inside the body) diagnostic imaging and therapeutics, and many companies have parallel programs to develop products for both categories. Hybritech and Centocor are leading such efforts; R&D is also being done by Genetic Systems, Xoma (Berkeley, Cal.), BioTherapy Systems (Mountain View, Cal.), NeoRx (Seattle), Biotherapeutics (Franklin, Tenn.), and Cetus (Emeryville, Cal.).

Centocor is developing products for use in diagnosing heart diseases and cancer. One such product, containing a radioactively tagged antibody to identify damaged heart tissue, will be introduced in clinical trials early this year in Italy, Austria, and the Netherlands—countries in which approval for marketing is usually speedier than in the United States. Solange Israel-Mintz, Centocor's director of marketing, projects a $25 million European market for this product by 1990; the U.S. market should surpass this level by the mid-1990s. "Since tumors can be found anywhere in the body and their biochemical signs are subtle, tumor imaging is more difficult than cardiac diagnosis, and it will take longer to develop," says Israel-Mintz. However, the technology could lead to the routine monitoring of cancer therapy and checking for metastasis (tumor spreading).

The same MAbs that are used to diagnose a tumor could potentially help destroy malignant cells. Most efforts toward developing MAb-based therapeutics are still in the developmental phase; for example, Xoma's product for treating melanoma by attaching a natural protein toxin to a MAb is undergoing clinical safety tests. But eventually, says Drake, *in vivo* therapy for all major cancers could earn at least $500 million annually in the U.S. alone. ***—Jeffrey L. Fox***

ANDRE ABECASSIS

At BioTherapy Systems, Richard Miller is planning new cancer therapies based on customized isotope–antibody combinations.

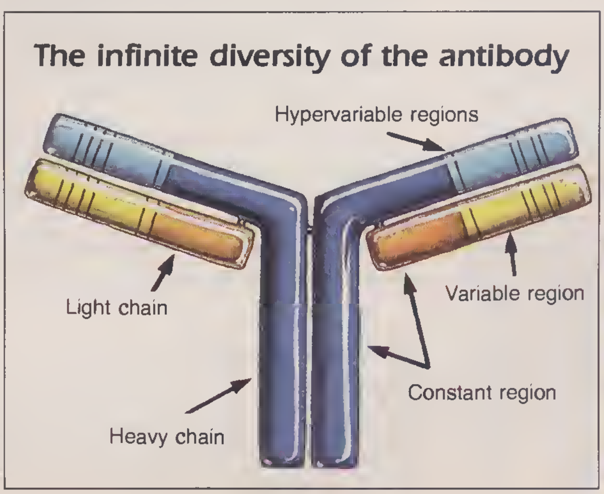
ceutical company Farmitalia Carlo Erba to develop immunoconjugates of the drug anthracycline.

Several new companies are devoted almost exclusively to immunoconjugation and related technology. "We've made conjugates that kill cancer cells *in vitro* at extremely low concentrations," says Paul Abrams, a former National Cancer Institute researcher and now vice-president and medical director of NeoRx. Formed in late 1984, the company is focusing on both imaging and therapy, and has recently filed patents on several of its conjugation methods. "We've recently started clinical trials with patients at the University of Washington," says Abrams. He also anticipates FDA approval on NeoRx's first products sometime in 1987.

Another promising immunoconjugate was reported last year by Eli Lilly in Indianapolis, although the details of the linkage technology were not disclosed. The product combines Lilly's anticancer drug vinblastine with a proprietary antibody called KS-1/4 (developed for Lilly by Scripps Clinic) that is specific to a type of cancer cell known as adenocarcinoma. The cancer cell is apparently displayed in about 37% of all tumors, and is a major component of 94% of prostate cancers and 82% of breast tumors.

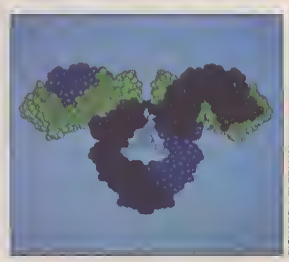
Clinical trials of the immunoconjugate (called KS-1/4 DAVLB) are now under way in lung-cancer patients. If even half of them respond to the therapy, the implications could be staggering—both for cancer patients and for Lilly. "We estimate that KS-1/4 DAVLB will be priced at about $4000 per gram," says Patricia P. Lea, vice-president of Salomon Brothers, an investment banking firm in New York. "We also assume that each course of treatment will require up to three grams of the immunoconjugate." Roughly 900,000 new cancer cases in 1985 involved the adenocarcinoma antigen, according to the American Cancer Society.

Although the main attraction of MAbs is their specificity, says NeoRx's Abrams, "we still have a problem with cross-reactivity. All antibodies attach to normal cells to some degree." One explanation lies in the nature of the malignant cell. Even a perfectly specific MAb (if it existed) could be outwitted by the cell's ability to mutate by changing its molecular profile and thus its antigenic characteristics. There is also evidence that some cancers might have more than one genetic origin. This phenome-



TOM BARRETT

Left: All antibodies consist of four amino acid-chains. Their great diversity is due to different amino acid sequences in the hypervariable (antigen-binding) regions. Below: A computer-drawn antibody.



RICHARD J. FLEDMAN

non (called multiclonality) is a troublesome exception to the common belief that all malignancies originate with a single defective cell. "But we think that no more than 5% of human cancers are truly multiclonal," says Richard A. Miller, vice-president and scientific director of BioTherapy Systems (BTS—Mountain View, Cal.). "Genetic mutation is much more common; it's one reason cancer cells are such good survivors." Consequently, says Hybritech's Martinis, it is unlikely that there will ever be a single MAb for every lung cancer.

BTS is now working with 25 lymphoma patients and has created hybridomas for 14 of them; the hybridomas are sent to Damon Biotech (which owns 80% of BTS), for actual MAb production. The entire process takes about six months, says Miller, during which time three different antibodies (each derived from different tumor cells from the patient) are created in an effort to circumvent the mutation problem. Clinical trials of these unconjugated antibodies will be conducted at Stanford University Medical Center.

Miller will also be working with conjugated antibodies. One example is the gamma emitter iodine-131, which is coupled directly to the antibody through covalent bonding. "We're concentrating on I-131 because its chemistry is very well known," says Miller. "The problem is its relative toxicity to the bone marrow. In the future we'll be evaluating less toxic isotopes—probably the beta emitter yttrium and alpha emitters such as astatine." These isotopes are not bound directly to the antibody, he says; rather, the protein is first reacted with a coupling agent (or chelator) such as the chemical DTPA; the isotope is then reacted to the other end of the DTPA molecule.

Clinical trials of the immunoconjugates are expected to get under way shortly at the Fred Hutchinson Cancer Center in Seattle.

Timed release. Researchers have a broad selection of isotope conjugates from which to choose. "We're still not sure which emitters will be best for every case," says Gary S. David, principal scientist at Hybritech. "There will probably be a combination of high- and low-energy emitters."

More important from a therapeutic standpoint is the antibody's specificity. In the case of unconjugated antibodies, cross-reactivity usually poses little hazard to the patient (although the protein's efficiency will be severely compromised); an attached toxin is an entirely different matter, since it will be delivered to certain healthy cells as well as diseased ones.

For the same reason, researchers must also make sure that the linkage between the two molecules is sturdy. "We don't want the toxin to detach from the antibody in the circulatory system," says NeoRx's Abrams. Ideally, the conjugation should also provide for the release of the drug molecule into the target once the antibody has bound to the cell. Such carefully timed releases are achieved not by one conjugation method but by several, including chelation and direct reaction between the two molecules.

Not surprisingly, few researchers will elaborate on specific methods of conjugation and release. One reason, of course, is the extreme secrecy surrounding such proprietary techniques; another reason, according to Hybritech's David, is simply that so little is known about conjugation chemistry and *in vivo* stability. The "best" linkage technique for a particular application will probably depend on a combination of factors: the nature of the antibody–antigen bond, the patient's body chemistry, and the chemical characteristics of the antibody and its cargo. Nor are researchers convinced that a conjugated toxin molecule must always detach from the antibody—there may be cases in which the entire conjugate is simply ingested into the target cell.

Another high priority, says Abrams, is to establish therapeutic "windows"—the range of dosages for each conjugate (which could also vary with the patient) below which the therapy is ineffective and above which it becomes hazardous.

There are several reasons why MAbs are being pegged so heavily to cancer therapy, aside from the disease's position as America's number-two killer. One is that much more is known about cancer than about other autoimmune diseases (disorders in which the patient is apparently assaulted by his own immune system), such as multiple sclerosis (MS) and severe arthritis. MS presents a special problem, moreover; unlike the usually progressive cancers, the symptoms of the disease normally wax and wane. It is therefore difficult to correlate results with treatment.

Another reason is that most of the cancer patients slated for MAb therapy literally have no alternative. "It sounds insensitive," says one company spokesperson, "but these patients really have nothing to lose. Thus we think that the government approval process might move a little faster as well."

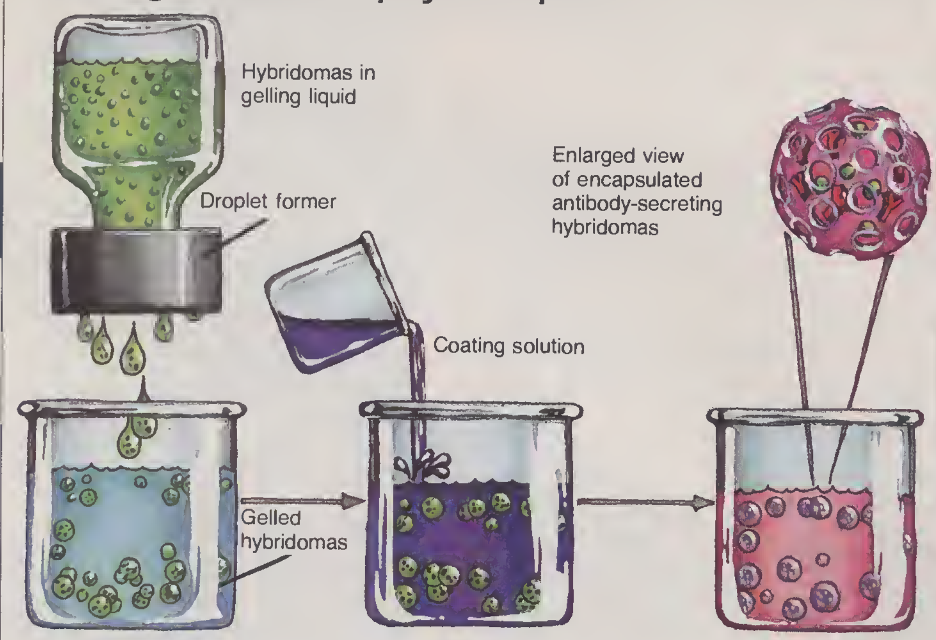
Scale-up problems. A growing therapeutic role for MAbs implies a demand for large and regular supplies. This is where most companies acknowledge serious problems in current production methods. World monoclonal production in 1985 totaled only about 2000 grams (about four pounds), according to Michael A. Boss, Celltech's cell culture business manager. Says BioResponse's Fouron, "That's enough for today's monoclonal-based diagnostic kits, which use very tiny amounts. But new pharmaceuticals will require several grams per patient."

One reason large-scale antibody production is often so complex is that hybridomas are living cells; as such, they are not governed by the same manufacturing principles as microprocessors or wing nuts. In conventional cell culture—that is, in glass vessels filled with liquid nutrients—every hybridoma line expresses its own peculiar preferences for nutrient and other culture conditions. "Every new hybridoma is largely an unknown for the company trying to produce MAbs from it," says Damon Biotech's Webb. "Some hybridomas grow best by anchoring themselves to a solid surface, for example, whereas others prefer to float freely. It often takes a long time to arrive at the best combination of factors." What's more, researchers have yet to achieve the high cell densities (typically more than a billion cells per milliliter) that simulate cells' natural environment.

Antibodies can also be grown in mice by injecting the hybridomas into the animals' abdominal cavities. The cells often thrive in such "natural" environments, with each mouse typically producing up to 40 milligrams of antibody; however, the recovered proteins inevitably contain some of the mouse's genes. The contamination has little or no effect on *in vitro* applications but could possibly provoke severe immunogenic reactions in patients. Mouse antibodies are also limited by sheer economics, says Paul J. Vasington, president of Karyon Technologies (Norwood, Mass.): "Unlike cell culture, there's no economy of scale. Mice are expensive to maintain, and the cost per gram of antibody doesn't fall with larger numbers."

For the past four years, Damon has touted its own proprietary method, called Encapcel, for inducing hybridomas to produce large amounts of antibody while enclosed in tiny hollow spheres. Hybridomas are first placed in a solution of biocompatible alginate (a chemical derived from brown algae), then encapsulated in a starchy polymer. The capsule's porosity allows gases and nutrients to flow into the cells, and waste products to flow out. When the antibodies reach a predetermined density, the capsules are broken open to retrieve the proteins. Damon claims that because of the protective coating and the high hybridoma densities achieved within the capsules, antibody yields have sometimes been hundreds

Raising antibodies in polymer capsules



In Damon Biotech's Encapcel cell culture system (left), antibody-secreting hybridomas are coated with a compatible chemical, then with a porous polymer "shell" that promotes high antibody production rates. The method will also be used to make recombinant DNA products, says Damon's Nigel Webb (above).

of times higher than in other cell culture systems.

Karyon Technologies—which Vasington characterizes as a cell culture company rather than a monoclonal producer—uses a similar method to grow antibodies for its clients. Called gel entrapment, the method embeds the hybridomas in a gel-like biocompatible alginate. Unlike Encapcel, however, it does not entail surrounding the cells with polymers; as a result, says Vasington, labor and capital costs are lower and cell densities are very high—up to 40 million cells per milliliter.

England's Celltech, which claims to run the world's largest MAb facility, has developed a "deep tank fermenter" that suspends the hybridomas in a proprietary culture medium. "There are several advantages to this system," says Boss, "including lower production costs, the ability to quickly scale up the process, and automated control." The company is making MAbs in a 1000-liter fermenter (reportedly yielding 100 grams of antibody in a relatively short two weeks) and is now building a 10,000-liter unit.

Throwing down the gauntlet. Given monoclonals' enormous potential in the healthcare marketplace, it is not surprising that many large pharmaceutical and chemical producers are developing their own MAb capabilities. Some observers doubt that such firms will be able to utilize the technology, because they are geared to making products in huge continuous processes, while MAbs are run in relatively small batches that can be completely different from one another. But the large companies' response is to team up with the smaller MAb producers, offering their marketing muscle and regulatory experience in exchange for MAb licenses or a share in the revenues. For example, Boots, Britain's largest producer of pharmaceuticals and diagnostics, recently signed a 50-50 joint venture with Celltech. Another path, of course, is outright acquisition, such as last year's Lilly-Hybritech arrangement.

Most MAb companies, however, are intent on developing proprietary processes and products. One logical route is to expand their capabilities into technologically related recombinant DNA programs, or even to merge the two technologies into a new one. Damon Biotech, for instance, plans to use its Encapcel cell culture method to grow recombinant DNA products, such as TPA (tissue plasminogen activator, a naturally occuring chemical that may help dissolve blood clots in coronary arteries). The work will probably be conducted in Damon's new facility in Livingston, Scotland, beginning next year.

Eight-year-old Hybritech is another example. Already established as one of the nation's key *in vitro* MAb producers through its Icon and Tandem lines of diagnostic kits, the company hired its first genetic engineering specialist last summer. "We had always intended to move into therapeutics," says David, alluding to the connection between recombinant DNA and healthcare. "There is a danger of spreading oneself too thin, of course, but we plan to at first limit our genetic engineering work to MAb-related programs"—producing antibodies through recombinant bacteria, for instance, or even designing entirely new MAbs through protein engineering.

Not all the new business will be hybridoma-related. Although BioResponse regards itself as primarily a MAb company, Fouron says that "our real business is growing cells. Only about 30% of the protein we recover from those cells is antibody; the rest is other kinds of protein" that may be commercially valuable. This suggests the possibility of creating or acquiring proprietary genes to be expressed in the company's cellular "protein factories." And while many genetic engineering companies are concentrating on bacterial cells to express these genes, BioResponse is focusing on mammalian cells. "Bacteria simply don't have the cellular 'machinery' to make a lot of different proteins," says Fouron. "Mammalian cells can produce virtually any protein as long as they're grown properly."

Considering the rapid pace of innovation in the MAb industry over just the past decade, any attempt to predict the next round of changes seems foolhardy. Clearly, an enormous amount of technical work remains before MAbs' full potential can be realized. It also seems certain that at least some companies will change course repeatedly before finding a suitable marketing slot. The ultimate payoff, however, is enormous—both for the companies themselves and, more important, for the hundreds of thousands of patients for whom MAbs may be not simply the best hope, but the only hope. □

For further information see **RESOURCES**, *p. 69.*

WHY IVAN CAN'T COMPUTE

The Soviets' "computer revolution" is running into industrial and political red tape

Last spring, the president of the Soviet Academy of Sciences, Anatoly Alexandrov, announced a computer education effort massive enough to rival the literacy campaign mounted after the Russian Revolution. The aim is to achieve computer literacy among all high school graduates in the Soviet Union by the end of this century. But the campaign has been slow in getting off the ground. At the country's 64,000 high schools, where there are more than 8 million students in the ninth and tenth grades alone, only a thousand microcomputers have been allocated for the 1985–86 school year. Soviet newspaper editorials have decried both the failure to select a standard computer model for education and the absence of adequate texts for teaching computer technology.

This effort to promote mass computer literacy is intended only to introduce future Soviet workers, managers and consumers to computers; even if successful, it will do little to correct some of the more serious barriers to applying computers, such as a reliance on production plans and quotas that discourages long-term investment in favor of short-term performance. "You still have to convince enterprise directors to install computers," says Hans-Lothar Altmann, a Soviet trade expert at the Osteuropa Institut in Munich. "They are interested in fulfilling their production targets now, not in 15 years. They see computers as a disruption of production processes."

by Maxine Pollack and Ross Alan Stapleton

Thus the advent of computers has barely touched life in the USSR outside of defense industries and the military. Despite an already large and diversified computer industry, Western experts place the Soviets behind the West in both technology and application by as much as a decade. Only recently has the term *personal computer* appeared in Soviet literature, and then only in the context of "collective use," as applied either to engineering workstations or to the few computers in educational laboratories. The idea of individual ownership of even the simplest microcomputer is virtually nonexistent in the USSR. Some observers maintain that Soviet leaders are largely to blame—that they see "personal" computing as a security threat and so discourage the use of PCs. "In a system that inhibits individual initiative and sees information as something dangerous and undesirable, you

Ninth-graders in Novosibirsk's School No. 166 come to grips with the Agat, the Russian version of the Apple II.

TASS FROM SOVFOTO

EASTFOTO

A technician checks out Czechoslovakian SM 50/40 microcomputers—units based on a copy of an 8-bit Intel 8080 processor.

can't have this kind of revolution," says Vladimir Sobell, a Munich-based researcher. But the fact is that the USSR remains technically incapable of producing microcomputers that compare either in quality or in quantity with those of the West.

The Soviets entered the computer age in the early 1960s, with a first generation of computers that matched concurrent developments in the U.S. and Great Britain. Subsequently, progress has been much slower than in the West. Two major computer programs within Comecon (the Eastern "Common Market") have evolved, encompassing the larger part of computer production in the Soviet bloc. The first is the ES (*Edinaya Systema*, or Unified System) series of mainframe computers. The second is the SM (*Systema Malykh*, or Small System) program, which covers most of the minicomputers and a number of the microcomputers produced by Comecon countries. These two programs grew out of a previously chaotic industry producing a number of incompatible families with widely varying levels of support.

The ES program includes all the Comecon members except Romania, which has preferred to remain apart from most of the Comecon computer efforts. The program, now producing its third series of machines, is based almost entirely on the duplication of IBM mainframes. The first phase, the Ryad-I (or Series-I) machines, patterned after the IBM System/360 series, began in the early 1970s. The Ryad-II machines, based on the IBM System/370 series, first appeared in the late 1970s and early 1980s. These computers were software-compatible within the series and with the earlier Ryad-I computers. The Ryad-III phase was reportedly announced in 1976—but the first production models have only just begun to appear, and little information on them is available.

Overall, the ES program might be seen as a relative success for the Comecon nations; it has produced a line of software-compatible systems, a tightly integrated range of peripherals, and the necessary system software. But the ES machines show no great innovation; they are copies of well-known Western series that have since been superseded. In addition, the ES computers are less reliable than the IBM originals.

The SM program, which began with four minicomputer models based on DEC and Hewlett-Packard machines, has adopted the DEC PDP-11 architecture as a standard. But this program is far less homogeneous than the ES program; it includes many mini- and microcomputers based on a number of indigenous microprocessors that are themselves duplicates of Western integrated circuits.

Many computers have been produced outside these two major programs. The SM series does not include the Agat microcomputer (a copy of the Apple II) and some high-speed machines, such as array processors, that the Soviets are known to have constructed. Overall, Comecon's microcomputer programs have been rather uncoordinated. It's possible that a third Comecon program will develop to incorporate modern microcomputer architectures. It's also possible that future microcomputers could be absorbed by the SM program. The latter is less likely, because of interministerial rivalry: The Ministry of the Radio Industry, which oversees the ES program, produces the microcomputers most likely to be adopted for education and scientific workstations; yet the SM program is controlled by the Ministry of Instrument Building, Automation, and Control Systems.

Both the ES and SM programs are multinational, with the Soviet Union playing a major role in coordination. The Comecon members have each chosen an area of specialization, such as floppy disk drives in Hungary and hard disk drives in Bulgaria. Hungary has also devoted a sizable effort to software and is virtually alone in the Soviet bloc in producing software that is sold to the West. Hungary's most successful product has been the M-PROLOG system, a version of the Western-developed PROLOG logic-programming language used in artificial intelligence applications and adopted by the Japanese for their Fifth Generation project. M-PROLOG has been sold in France, West Germany, Canada, and Japan. Currently, the Hungarians are working on the final components of a seven-module software-engineering system called SOFTORG, developed in cooperation with a West German firm, Software Engineering GmbH. SOFTORG is designed for Western IBM and DEC VAX system users and could be run on indigenous Comecon ES computers.

One of the critical problems facing the Soviet computer industry is that R&D is separated from production—both by geography and by ministerial responsibility. What's more, the Soviet bloc has been weak in the production of electronic components—especially semiconductors—on which computer manufacture heavily depends. "The supply of better-quality components is low, and the armaments industry enjoys first priority," writes Z. A. Siemaszko, an engineer at the British aerospace firm of Babcock-Bristol Ltd., in a recent study of Soviet electronics. "Civilian industries are supplied with leftovers." But "the most important single

TASS FROM SOVFOTO

EASTFOTO

Hungary's Videoton Electronics produces a range of 8-bit and 16-bit microcomputers outside the official Soviet computer series.

The Soviet ES-1020 mainframe physically and functionally resembles the IBM System/360 Model 40.

The Ukrainian Academy of Sciences in Kiev provides programming courses to help prepare local high school students for Academy careers.

TASS FROM SOVFOTO

factor inhibiting the pace and scope of innovation," he maintains, "is the absence of competition and user feedback." After the Soviet Union, the strongest IC makers within Comecon are East Germany and Czechoslovakia. Virtually all the microprocessors now being produced in Comecon countries appear to be copies of Western chips. The Soviet bloc countries seem to be relying on the experience of the West rather than on assessments of their own internal markets.

But even if the Soviet bloc as a whole boosted its computer production, software would still be a problem. According to reports from visiting Western computer experts, much of the software in the Soviet Union and Eastern Europe is not merely modeled on Western packages but directly copied to the extent that programming and inputs must be entered in English. Again, a reliance on directly transplantable features of the Western industries has left Comecon's indigenous software capability poor at best.

In the face of critical problems in both hardware and software production, the speed with which computers proliferate in Comecon countries will depend primarily on the extent to which those countries gain access to more sophisticated Western technology. In the past, Eastward transfers have been restricted not only by Western trade embargoes but also by the limited purchasing power of each Comecon country. But things may be changing.

"Although it's a mistake to think the boom period of the 1970s will ever be repeated, there's an upturn in purchases of Western technology by the East, whose financial situation is now eased," observes Helgard Wienert, an expert on East–West technology transfer at the Organization for Economic Cooperation and Development in Paris. "The prospects are limited, since Eastern Europe is not about to make far-reaching reforms, but trade will take off again at a lower volume level." The East's "dependence on the West is bound to remain considerable," says Vladimir Sobell. At present, he notes, only 55–60% of all specialized materials needed for electronics production are wholly covered by exports within Comecon. Without radical economic reforms to introduce new incentives and innovation in this sector, a window on the West will have to be kept open. □

Maxine Pollack is a freelance journalist based in Munich. Ross Alan Stapleton is a researcher in Soviet technology at the University of Arizona (Tucson).

For further information see **RESOURCES,** *p. 69.*

THE NEW UNDERGROUND

Advanced technology is helping tunnelers work faster, tackle once inaccessible ground, and even link countries separated by water

by Sara Neustadtl

More than 180 years after Napoleon ordered his engineers to draw up blueprints, tunnelers are poised to conquer the English Channel. Britain and France agreed last year upon guidelines for a "permanent link" to span the channel at its narrowest point (22 miles across), and early this year the governments will select the winner from among a handful of proposals for financing, building, and operating the venture. Although the bids include plans for a huge suspension bridge and a fleet of "superferries," some form of tunnel is the odds-on favorite. Construction will likely begin next year, with completion scheduled for as early as 1992.

On the other side of the globe, another island nation recently completed a mammoth tunneling project. On March 10, 1984, workers first saw light at the end of the world's longest tunnel: the 34-mile-long Seikan railroad tunnel connecting Japan's main island of Honshu with the northern island of Hokkaido. More than half of the tunnel lies beneath the Tsugaru Strait, running through difficult and dangerous ground whose excavation taxed both men and machines. Finishing touches are under way, and trains will start using the tunnel next year, more than two decades after construction began.

Tunnels—for subways, railroads, and highways—are big business; just the 90 largest transportation tunnels planned or under construction around the world represent at least $74 billion of investment. But perhaps befitting an industry whose projects usually take years to complete, tunneling technology has progressed slowly rather than by leaps. "Compared with advances in industries like electronics and computers, new techniques for digging a hole in the ground must seem few and far between," the British journal *Tunnels & Tunnelling* editorialized recently. "But there have been some, and they are significant." Equipped with a variety of machines and methods developed or refined over the last decade or so, tunnelers are working faster and safer than ever. They are boring through ground—especially soft, waterlogged soils—that once posed insurmountable problems. And improvements in equipment reliability and consistency have reduced some of the financial risks that have long been associated with tunneling.

Still, tunnels remain terrifically expensive. For example, Fred Rutyna of the Transportation Systems Center, part of the U.S. Department of Transportation, estimates that building a subway beneath Wilshire Blvd. in Los Angeles will cost about $60 million per mile. Thus the fact that tunnels are never built when there is a reasonable above-ground option, combined with the recent shakiness of the world economy, has pushed the tunneling industry into the doldrums.

Some observers, however, see several rays of hope. John Landis, senior VP of Stone and Webster Engineering (Boston) and president of the American Society for Macro-Engineering, expects opportunities to open up in Southeast Asian countries and other developing nations where crowded cities, massive populations, and a lack of automobiles will necessitate building extensive underground transit systems. "We're bullish on tunnels," he says. "They save so much money in the long run that the investment will become very attractive to these governments." Moreover, technological advances may be opening the door at least slightly for private investors to back tunnel projects. The English Channel tunnel, for example, will be financed privately; investors maintain that greatly improved equipment performance and the tunnel's long income-producing lifetime make the risk worth taking.

The fundamental aim of tunneling, of course, is to drive through the ground a hole that will remain intact. But this aim can be furthered or confounded by the tunnel's "climate," which is established by the ground. Although tunnels are usually classified as "hard rock" or "soft ground," conditions spread over a continuum from loose sand and mud to rock with a hardness of 60,000 psi. Conditions often vary greatly in the same bore, with severely fractured zones found along fault planes in otherwise sound rock, for example. Engineers routinely drill preconstruction test holes from the surface to gauge underground conditions, and tunneling firms base their bids and equipment orders on the results. However, even the most thorough geotechnical evaluations sometimes miss features that will plague operations.

Once the tunnel is under way, test holes are sometimes drilled from the face into the ground ahead to provide a more detailed picture. Even then, unexpected geological conditions can cause trouble. Some rock

MCS SCANDINAVIA

A worker perches on the face of an immense boring machine being used to drive a highway tunnel in Norway. Opposite: the last rocks fall away as the machine breaks through.

may swell when exposed to air, and some soils squeeze inward, trapping a boring machine so tightly that it must be mined out. Gas leaks and uncontrolled flooding are also ever-present dangers. "My advice to clients is to always expect the unexpected," says Peter J. Tarkoy, a geotechnical consultant in Sherborn, Mass. "When you're in the hole, you're always on the edge of a new frontier."

While ground conditions determine which excavation technique will be used, most tunneling proceeds through similar stages: Workers prepare the ground as needed, excavate the hole, haul out the muck, and finally erect the initial supports and the permanent lining.

The Seikan tunnel, for example, runs mostly through soft, badly fractured rock that made the opening prone to cave-ins and flooding. The tunnelers thus relied extensively on a technique called grouting to stabilize the ground ahead before each round of excavation. Working from the tunnel's face, they drilled long holes that followed the projected route and injected a liquid mixture of cement and sodium silicate under high pressure. The grout spread through fissures in the rock and quickly hardened, filling the voids and bonding shards together to form a watertight zone strong enough to protect the tunnel. In the worst spots, workers pumped enough grout to form a reinforced zone six times as wide as the tunnel itself, a precaution that sometimes slowed progress to as little as 35 meters a month.

Grouting is the most commonly used method of ground improvement, and tunnelers can choose from a variety of materials according to their gelling time, pumpability, ease of use, environmental safety, and cost. Indeed, many grout manufacturers now analyze ground conditions in a tunnel and then concoct a customized mixture. While undersea tunnels and deep tunnels require that grouting be done from within, tunnelers more often inject grout from the surface through vertical holes drilled ahead of the face. Either way, however, tunnelers can never be quite sure whether the grout has done its job, even when water flow has apparently been stopped. Sometimes it fails. The Seikan tunnel, for example, suffered four major cave-ins despite its heavy grouting; one cave-in killed 34 workers, and another halted construction for a costly eight months.

Troublesome ground can also be stabilized and waterproofed by temporary freezing. As with grouting, workers drill holes down from the surface or horizontally from the face and fit them with pipe. Electric pumps then circulate a refrigerant—typically liquid nitrogen or calcium chloride brine—which freezes water in the pores between soil or rock particles to form an impervious mass of ice that can withstand the stresses of excavation. Tunnelers keep a watchful eye on the protective mass by using temperature sensors and ultrasonic monitors that measure the velocity of sound waves to determine whether they are traveling through water or through ice. When that portion of the tunnel has been bored and supports are in place, the ice is allowed to melt. Workers then advance the freezer pipes and repeat the cycle.

Drilling and blasting. To drive the Seikan tunnel, workers mainly used the drill-and-blast method, long a hallmark of tunneling.

After nearly two centuries of delay, tunnelers are now ready to conquer the English Channel.

But where men once used hand-held drills to tediously punch holes into the face, machines have taken over. Using a mobile "jumbo" outfitted with several boom-mounted hydraulic drills, tunnelers can readily produce a fixed pattern of up to 80 holes. Each hole is stuffed with several pounds of explosive—often a mixture of ammonium nitrate and fuel oil (ANFO)—and detonated in a controlled sequence from the center outward. The blast takes a bite that is remarkably predictable in shape and size.

Hydraulic drills, introduced in 1969 by the French firm Montabert, revolutionized drill-and-blast tunneling. The drills could penetrate rock twice as fast as their pneumatic predecessors, while consuming only half as much energy. A steady stream of refinements have improved their performance even more. "However, the efficiency of hydraulic jumbos, despite their many automatic features, still depends largely on the driller operating them," says Pertti Koivunen, research engineer at Tamrock. This Finnish company, along with the Swedish firm Atlas Copco, now dominates the manufacture of hydraulic drilling machines. "Differences of as much as 30% in hourly drilling rates have been observed," says Koivunen, "simply from the way the boom and drilling system are handled."

To boost efficiency, several companies are testing microprocessor-controlled drilling rigs. With Tamrock's jumbo, the first step is to position one of the drill-equipped booms with the aid of a laser beam. The microprocessor then calculates the rig's precise location relative to the axis of the tunnel, and the booms are moved to their correct positions according to a preprogrammed drilling pattern. After drilling to the specified depth, the boom automatically moves to the next spot and starts again. The operator monitors drilling activity on a visual display unit and can override the microprocessor to compensate for irregularities in the face. This system ensures that the "best driller" drills every shift, says Koivunen. He predicts that the first generation of microprocessor-controlled jumbos will be in common use by the end of the decade.

After blasting, the opening must be supported almost immediately. Workers in the Seikan tunnel used a long-established method: coating the rock with "shotcrete" (a sprayable mixture of cement, sand, water, and other materials), installing long bolts deep into the walls, and erecting massive steel arches that carry the load as the rock collapses onto them. But many tunnelers are switching to the New Austrian Tunneling Method (NATM), which takes advantage of the surrounding rock's inherent capacity for self-support rather than relying on the brute strength of steel arches. Despite its name, NATM was really developed more than 20 years ago by Austrian engineers for driving deep tunnels through the Alps. But in this staunchly conservative industry, the approach is still "new" for many tunnelers, especially in the U.S.

The NATM concept calls for spraying exposed rock immediately with a thin layer of shotcrete and installing bolts and other primary supports as needed. The key is providing enough support to keep the walls from caving in while allowing them to slowly settle. This relaxation releases internal stresses, and the rock gradually reaches equilibrium, taking on a natural permanency much like that of a cavern. Monitoring settlement is vital, so tunnelers outfit the walls and shotcrete lining with a host of instruments. If they find that the rock is compacting too rapidly, additional support is added. Because the permanent lining is installed only after the tunnel has stabilized, the lining can be much thinner and therefore less expensive. Costs are also greatly reduced because the excavated opening can be smaller; workers cut the tunnel almost to size rather than blasting out a large "overbreak" to allow room for the rock to drop onto the steel arches.

NATM made its U.S. debut in 1983 when Ilbau, an Austrian construction

LOUIS BENCZE

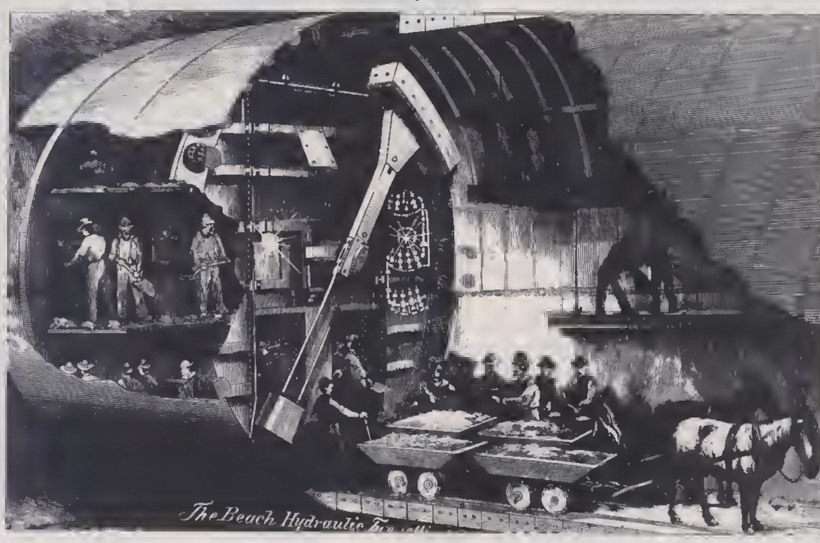
firm, won bids on subway tunnel projects in Pittsburgh and Washington, D.C. In Washington, the subway authority specified that conventional drill-and-blast should be used, and estimated the job's cost at $84 million. Ilbau beat out five U.S. contractors by bidding $52 million. However, the firm then submitted another proposal of only $48 million, based on using NATM, which local authorities agreed to after being convinced of its safety. Tunneling is now under way, with completion scheduled for next fall.

Because shotcrete plays such an important role in both NATM and other drill-and-blast methods, many companies are working to improve its application. Intradym, a Swiss firm, recently introduced a robot system that sprays walls more evenly than manual systems, and in half the time. A new type of shotcrete containing steel fibers, which adheres to rock more tightly, is starting to gain market share, while some manufacturers are testing carbon-fiber mixtures. Some contractors are also switching from dry to wet shotcrete in order to improve working conditions. With dry shotcrete, the powder is mixed with water in the nozzle of the sprayer, but some of the powder remains dry, creating thick clouds of unhealthful dust. Wet shotcrete is prepared outside the tunnel and hauled in.

Tunnel-boring machines, such as this new "mole" looming behind Richard Robbins, president of the Robbins Co., are able to chew through increasingly hard rock.

Mighty moles. While drill-and-blast techniques will remain important for the foreseeable future, tunnel-boring machines (TBMs), or "moles," are increasingly being used. TBMs rely mainly on brute force; a "cutterhead" driven by electric motors of up to 2400 horsepower turns against the rock, and dozens of carbon-steel disc cutters mounted on the cutterhead attack the face with up to 50,000 pounds of pressure. (The cutterhead can batter the face with several million pounds of

pressure to get through patches of especially hard rock.) Bearings allow the discs to roll over the rock to chip it, rather than grind it. The chips fall to the bottom of the tunnel, where the revolving cutterhead scoops them up and dumps them on moving belts that pass to the rear of the machine. "Muck trains," running on tracks that workers constantly advance behind the TBM, shuttle the chips to the surface.



BETTMAN ARCHIVE

A TBM advances somewhat like an inchworm: Hydraulic grippers push against the rock walls to hold the machine in place, then powerful cylinders thrust the cutterhead forward to make the cut; finally the cylinders pull back a bit, and the grippers reset farther along the walls to begin again. Because the machines disturb the rock less than blasting does, supporting the tunnel is often easier and less expensive.

TBMs were introduced in the late 1950s by James S. Robbins, founder of the Robbins Co. (Kent, Wash.), and have since undergone steady refinement. New machines chew through harder and harder rock, and when ground conditions are good they advance at a remarkable pace. For example, a mole could likely bore through the chalk beneath the English Channel at a 20-foot-per-hour clip, claims Richard Robbins, president of the company that has become the world's largest manufacturer of TBMs.

However, TBMs take up to a year to build, and cost millions of dollars, generally making them impractical for drives shorter than about a mile. And because every machine is custom-built according to the geological conditions and other requirements of a specific tunnel, their manufacture is as much art as engineering. "All our machines are prototypes," says Richard Lovat, Sr., owner-designer of Lovat Tunnel Equipment (Toronto). He says that most technological advances come not from the design engineer's drawing board but from discussions between the contractor (who describes his needs) and the equipment manufacturer (who tries to find a way to fill them). Thus a manufacturer's biggest selling point is the ability to produce new machinery that performs as promised, rather than the reputation of a particular off-the-shelf product.

Given the tunneling industry's current economic woes, Richard Robbins says machine manufacturers are being even more cautious than usual in pushing the technology ahead. They are simply refining existing designs, rather than devising radically new approaches. For example, Robbins is experimenting with new alloys for disc cutters. A trade-off must now be made between hardness and durability; alloys that cut faster tend to chip, requiring more frequent repair, but those that last longer chew the face more slowly.

"Shield machines" for boring through soft, waterlogged soil have advanced remarkably from earlier days.

Water-jet systems that enhance cutting could become more common on TBMs. Although researchers demonstrated long ago that water spurting at pressures of 14,500 psi easily slices through rock, the difficulty of controlling such systems has prevented them from replacing disc cutters. A better approach is to combine the two: Water jets operating at about 5000 psi can be used in tandem with disc cutters to improve chip removal, suppress dust, and reduce strain on the cutterhead by providing extra lubrication. But "applying water jets at this pressure will not be easy," cautions Richard Robbins. "For years, dust-suppression spray systems operating at several hundred psi have been used on TBM cutterheads, and they have been a major problem in terms of reliability."

Better ways to guide the massive, ungainly machines are also needed. An operator steers by painstakingly adjusting the rear support legs, shifting the machine up and down or from side to side. Most TBMs are equipped with a laser alignment system, in which a beam shining from behind passes through a crosshair mounted on the rear of the machine and strikes a grid in front of the operator. The operator tries to keep the beam focused on a dot marked on the grid, which represents the desired direction. But precision is hard to achieve, since the machine vibrates heavily and churns up dust that obscures the operator's view.

Zed Instruments (Surrey, England) has pioneered improved steering systems that take most of the judgment calls out of an operator's hands. Instead of having the operator watch a target, the Zed system beams the laser onto a photodiode array, allowing a microprocessor to determine the machine's position to within a few inches. Neither does the operator have to calculate his own course; the microprocessor compares the machine's current alignment with the desired path, and an LED display informs the operator how many millimeters he is steering off course.

Zed's system costs $60,000, while a conventional laser alignment system costs only about $50. But according to James Friant, manager of government projects for Robbins, the system's increased accuracy can pay for itself four or five times over on a single job. "Tunnels are usually designed several inches larger than required, to allow for inaccurate steering," he says. "If you know you can steer accurately, you can make your TBM a little smaller. You therefore need to haul out less muck, and you use less material for the lining." An increasing number of European contractors are using the Zed system, but U.S. tunnelers have been slow to follow: Although the system can do wonders when it's working, some contractors claim that it is prone to mechanical failure.

To improve the overall reliability of TBMs, manufacturers could install electronic systems that would monitor a machine's mechanical functions. Richard Robbins says that the need for maintenance could be indicated by early warning signals from key components, or cutters might be changed when sensors reported imminent failure. "Unfortunately," he cautions, "the underground excavation environment

is probably the worst in which to use electronic systems. Severe vibration, dust, humidity, and temperature fluctuations make equipment designed for conventional factories impractical." He expects that problems with electronic steering and monitoring systems will be overcome by sturdier packaging and improved design. Then, says Robbins, "just as automatic pilots can steer airplanes more accurately than a human pilot can, the TBM will be controlled to produce a straighter tunnel with lower cutting costs."

Soft-ground machines. Many of the world's cities, especially those near coastlines, are built not on rock but on spongy, waterlogged soil. Until less than a decade ago, soft ground presented hard problems—and was often inaccessible to tunnelers. The soil tries to fill in an excavation, endangering the tunnelers and causing ground movement that threatens buildings on the surface.

The solution is to enclose tunneling activity within a shelter, or "shield," that holds the ground in place during excavation. Sir Marc Isambard Brunel pioneered the shield in the early 1800s while digging a tunnel in London beneath the Thames River. Brunel's shield was essentially an open-ended cylinder with vertical timbers that formed a wall against the tunnel's face. Workers would remove a timber, dig in front of it, replace it several feet forward, and then move on to the next one. When the entire face had been excavated, the workers would jack the cylinder forward from the brickwork lining erected in its wake and begin again. Today's shield machines are basically mechanized variations of Brunel's design.

Hydraulic drills mounted on mobile rigs, such as this "jumbo" at work in a Washington, D.C., subway, increase the efficiency of drill-and-blast tunneling.

Working beneath the water table poses another problem besides shifting soil: High water pressure can cause rapid flooding through the tunnel's exposed face. Tunnelers for years solved this by filling the entire opening with compressed air, a method that still finds occasional use. However, workers are limited in how long they can work each shift, because they must take time to decompress: Coming to the surface too soon can trigger the bends—formation of deadly nitrogen bubbles in the bloodstream. Tunnel blowouts, in which the face suddenly ruptures and the pressurized air rushes out, are also a constant threat. The new shield machines get around these problems by using "closed faces"; that is, increased pressure is maintained only in a small chamber immediately behind the cutterhead, which is tightly sealed off from the main opening.

The British developed the first closed-face shield machine, and German engineers have followed suit. But Japanese companies have taken the technology the farthest. Several types of machines are now available for various ground conditions:

- *Slurry shield* machines maintain pressure on the face by pumping a slurry, sometimes containing a special clay called bentonite, into the front chamber. Some of the slurry penetrates the face and bonds the soil particles together. A rotating cutterhead, equipped with "drag bits" that scoop rather than chip, does the excavation. The loosened soil mixes with slurry still in the chamber, and the mixture is pumped through pipes to the surface. The muck is then separated from the slurry and prepared for disposal, while the slurry is recycled back to the face. Behind the machine, workers usually line the tunnel with prefabricated concrete rings.
- *Earth pressure-balance shield* machines use excavated soil rather than a slurry to maintain pressure at the face. Soil enters the front chamber through slits in the cutterhead, where it is compacted to support the face and keep out water. At the same time, an equal amount of soil is removed from the rear of the chamber by a rotating auger. The tunnelers' challenge is to allow the machine to move fast enough to be efficient without jeopardizing the all-important pressure: too fast, and the ground above the tunnel can sink; too slow, and time is lost. Computerized pressure gauges help workers keep on top of this trade-off.
- *Slime shield* machines are essentially hybrids of the first two machines, since they use soil to support the face but need a slurry to function. They are used for drives through sandy soils that

may not "flow" freely enough and may not compact properly in the chamber. A small amount of clay slurry—the slime—is therefore injected into the chamber to mix with the soil and modify its behavior. However, the slime/muck mixture that leaves the machine is a pollutant that generally requires treatment before disposal. A slime shield machine made by Hitachi Zosen of Japan is now driving two 2500-foot-long subway tunnels under the Anacostia River in Washington, D.C. This marks the first use of any kind of shield machine for driving a transportation tunnel in the United States.

While these machines speed through soil that is uniformly soft, they have trouble handling "mixed ground" embedded with rocks of cobblestone size. Workers have to mine their way to the front of the machine and dig through the rocky stretch by hand. Several Japanese companies, as well as Lovat in Canada, are devising machines to cope with such conditions. Some have cutterheads equipped with special disc cutters that can crush cobbles. Others have cutterheads made with hatches; cobbles can be pulled in through the openings, or workers can climb through to excavate manually.

Streamlining the system. Machines that cut faster are only part of the answer in driving tunnels more efficiently, and tunnelers are looking for ways to streamline the rest of the system. For example, the German firm Westfalia Lunen has developed a rock-boring machine that semiautomatically creates the tunnel's supportive lining as it moves along. The shielded machine houses a concrete extruder in its tail section. Workers install a ring-shaped steel framework against the exposed walls at the tail and inject concrete reinforced with steel fibers into the gap between the frame and the rock. The machine then moves forward, workers install another ring and inject more concrete, and so on for 12 rings. By then the concrete behind the first ring has dried, so workers recycle the ring to the front. Although the machine has received only limited use to date, David Martin, editor of *Tunnels & Tunnelling*, maintains that "it may well be the forerunner of things to come." Several Japanese companies are developing similar machines for soft-ground tunneling.

U.S. researchers have taken the idea farther. Foster-Miller Associates (Waltham, Mass.), working under a contract from the federal Urban Mass Transit Authority, has developed a completely automatic lining system: The shield itself serves as the framework to hold the fast-setting concrete, eliminating the need for manual installation. The shield telescopes, with the rear section staying in place while the front section proceeds forward with the excavation. Once the concrete is set, the shield returns to its original position and the process is repeated. However, some U.S. contractors have expressed doubts about various aspects of the system's performance, and it has yet to be used on a commercial project.

Since a tunnel is really a factory in a hole, smoother coordination is a potentially important route to higher productivity. "Horse sense, not horsepower" is the key to efficiency, says geotechnical consultant Peter Tarkoy. Thus various management-oriented techniques are slowly finding their way into the rough-and-tumble world of tunneling. For example, Tarkoy has pioneered the use of microcomputers to simulate a job before the contractor digs any ground. (Although Tarkoy wrote some of the early programs, he says that conventional spreadsheet software can be adapted for many applications.) Given geotechnical data about the site, estimates of machine performance or drill-and-blast operations, and information culled from the contractor's previous experience with daily activities such as advancing muck trains and installing utilities, he produces graphics displays of the tunnel's likely progress.

"Horse sense, not horsepower" can be an important key to higher productivity in tunneling.

The contractor can therefore choose the optimal combination of equipment, labor, and daily operations—and sharpen his bid accordingly. Once the drive is under way, the contractor can compare actual progress with projected rates in order to ward off sources of trouble, such as taking too much time placing supports or clearing muck.

Tarkoy examines projects after they have been completed as well, enabling contractors to identify operational improvements for future jobs. For example, in one tunneling project in Washington state, shuttling the single muck train in and out proved to account for a hefty 12% of downtime. The contractor eliminated this bottleneck on his next project by installing an extra set of track under the muck conveyor so a train could pull in to be loaded while the other headed for the surface. Tarkoy's after-the-fact analyses are also used in settling "differing-site-conditions" claims, which contractors file to get extra payment when they think ground conditions not identified in the contract by the owner's design engineer delayed completion. The graphics help court investigators visualize how much downtime was due to geology and how much might have been avoided.

Tunnelers can even take the factory *out* of the hole, especially for crossing under rivers and other bodies of water. So-called sunken-tube tunnels are built with prefabricated shells manufactured in construction yards and floated to where they are needed. The shells, which are hundreds of feet long and made of concrete, or steel lined with concrete, are then sunk and buried in trenches dredged on the bottom. Since 1910, when tunnelers laid a half-mile-long railroad tube under the Detroit River to connect Detroit with Windsor, Ontario, dozens of sunken-tube tunnels have been built worldwide. But the grandest project may be in the offing. A group called Euroroute, one of the leading contenders in the bidding to build the English Channel tunnel, plans to lay a 13-mile-long sunken-tube highway tunnel between man-made islands constructed about five miles offshore. Bridges will stretch from each coast to the islands, and cars will enter the tunnel via ramps spiraling through their interior. A separate sunken-tube railroad tunnel will follow a parallel route across the entire channel.

Now that the English Channel tunnel seems imminent and the record-setting Seikan tunnel is nearly complete, tunnelers may begin looking with renewed optimism at a number of awesome projects. For example, the Japan-Korea Tunnel Research Institute is boring test holes beneath the 230-kilometer Korea Strait, which separates the two nations. Spanish and Moroccan engineers are studying the feasibility of a 50-kilometer transportation tunnel beneath the Strait of Gibraltar between Cadiz and Tangier. Less developed schemes include a tunnel beneath the Irish Sea to connect Britain and Ireland and a tunnel at the Strait of Messina between Sicily and the Italian mainland. Driving these tunnels would push the abilities of today's tunneling techniques to the limit—yet only five or ten years ago they would have been all but impossible. □

Sara Neustadtl is a Boston writer who often reports on the effects of industrialization on remote parts of the world.

For further information see **RESOURCES,** *p. 69.*

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PEDALING NEW WARES

Bicycle makers in the U.S. are leading the race for faster, lighter designs

The recent resurgence of bicycling in the U.S. as both an adult recreation and a competitive sport is fueling demand for high-performance machines. Among the most innovative manufacturers are American specialty bike companies, whose use of new materials and inventions is outpacing the more traditional European cycle makers, often considered the leaders by serious bikers. Lighter and stronger frames, more powerful crank sets, innovative gear trains, and even more comfortable saddles are some of the results of the push for bikes that are lighter, faster, easier to ride, and more durable than ever.

Most refinements in design and construction appear first in road-racing bicycles, those used in organized competition on public streets. Since recreational riders purchase considerable numbers of mostly unmodified road racers, the effect of new developments on the consumer scene is fairly rapid. In fact, cycling enthusiasts will often adopt innovations more rapidly than the racing fraternity.

A road-racing bicycle is essentially a subspecies of the familiar ten-speed bike, the kind with downturned "drop" handlebars, although nowadays most racers have twelve rather than ten gears. The modern road racer was developed in Europe in the late 1930s and has changed little until recently. Most quality road racers are still assembled by hand out of thin steel pipes and held together by silver solder and tubular lugs—pipe fittings, as it were. The steels have improved over the years—chrome molybdenum is now standard for high-performance bikes—but the assembly methods remain unchanged.

by Daniel Sweeney

Patriotic road racer by U.S. bicycle maker Trek has an epoxy-glued aluminum frame weighing just 3½ pounds, and retails for $1299. Trek claims that the frame is as strong as steel.

Aluminum frames were attempted as far back as the 1890s; more recently, frames made of titanium, bamboo, carbon fiber, and various plastics have been tried. Teledyne introduced a titanium frame, and Exxon developed a graphite frame about a decade ago, but the products were short-lived. "Both materials are very difficult to work and enormously expensive," says Mike Melton, coordinator of the technical development center for the U.S. Olympic cycling team.

Aluminum is significantly lighter than steel but, in unalloyed form, is much softer and more difficult to weld. However, new alloys and high-strength adhesives developed for the aerospace industry are changing all that. For example, Trek (Waterloo, Wis.), a leading U.S. maker of high-performance bikes, recently introduced an epoxy-glued aluminum frame that is light—weighing 3½ pounds compared with 8 pounds for a conventional steel frame—and, claims the company, is as strong as a steel bike. The frame's tubes are made from True Temper 7000-series aluminum alloy, a material used for the frames of jet aircraft. The stiffness-to-weight ratio of this alloy is nearly double that of the 6000-series alloys used in earlier aluminum bikes, resulting in an exceptionally light, stiff frame. A rigid frame, like a stiff suspension on a sportscar, is more stable when cornering; and because it flexes less when the rider pedals, more power is transmitted to the rear wheel.

Stiff frames, however, are often uncomfortable to ride, because they transmit road shocks to the rider through the frame. But Trek's designers reasoned that since lateral rigidity was the primary factor in promoting efficient power transfer to the rear wheel, superior comfort could be achieved—without sacrificing sprinting or handling ability—by decreasing vertical rigidity. To this end, more flexible 6000-series aluminum alloy front forks were developed for the Trek 2000, while the frame proper was made of the stiffer 7000 alloy. The bicycle has met with wide acceptance among serious enthusiasts.

Aluminum frames are also made by Cannondale (Georgetown, Conn.) and Klein (Chehalis, Wash.), using larger-gauge tubing of 6000-series alloy that can be welded instead of glued. Several

European manufacturers (notably Peugeot and Vitus in France and Alan in Italy) have introduced aluminum frames, and major Japanese manufacturers such as Nishiki, Centurion, Miyata, and Fuji are expected to enter the market within the year.

Despite the potential Japanese threat, Bevil Hogg, Trek's executive vice-president, is not alarmed. "The Japanese are heavily committed to steel," he says. "They're getting into aluminum hastily, using the older technology of welding."

In any case, Hogg believes that aluminum frames may be just a phase in the bicycle world, despite the apparent success of the Trek 2000 bicycle. "How long did aluminum tennis rackets last?" he asks. "Laminates employing such materials as Kevlar and carbon fiber may be superior. They've already proven themselves in other types of sporting goods."

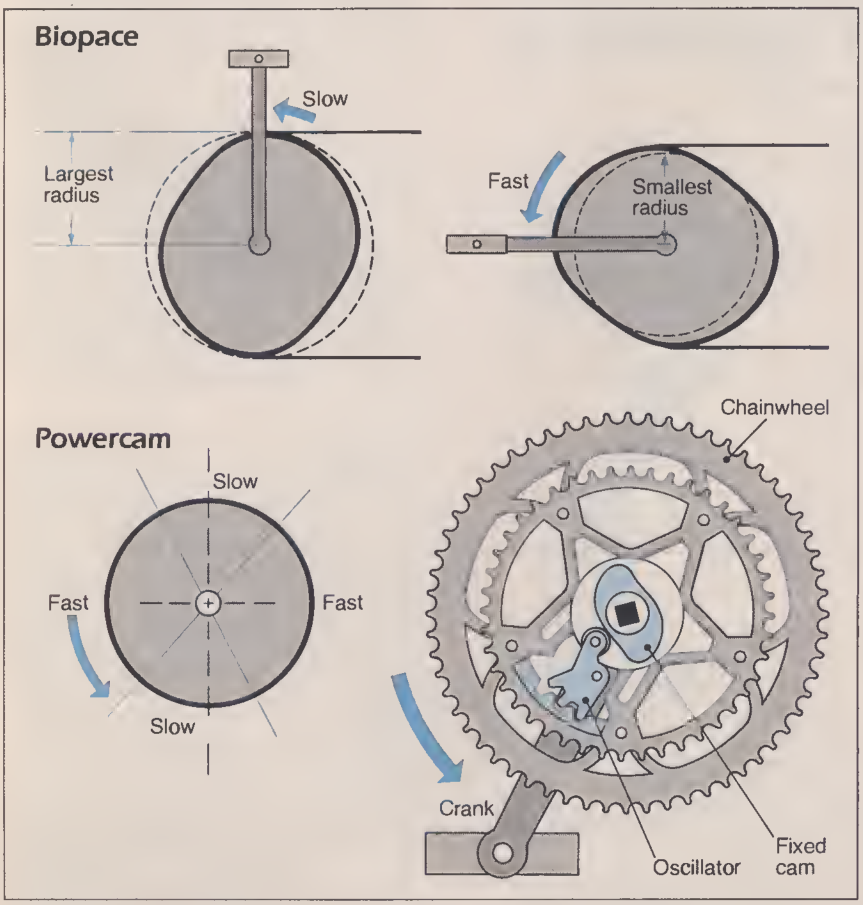
Indeed, carbon-fiber frames have already been introduced by Alan and Vitus, and Trek expects to produce such a frame later this year. Carbon-fiber composites are widely used in aircraft construction because they are immensely stiff and extremely light. While these are desirable properties for a bicycle frame as well, high costs pose a barrier. "The prices of Kevlar, carbon fiber, and boron fiber are several times those of steel and aluminum," says the Olympic team's Melton. However, since high-performance bikes are hand-built, the raw-material cost is a relatively small proportion of the total manufacturing cost.

Manufacturing techniques are also problematic. "Joining carbon fibers to steel is very difficult," says Melton, "because the different coefficients of expansion of steel and carbon fiber set up great stresses in the frame." Nonetheless, the aircraft adhesives used to join the carbon-fiber tubes to steel or aluminum lugs are so strong that some manufacturers think the joints will be able to withstand any stresses caused by differential expansion. So, despite Melton's reservations, composite frames are beginning to appear on the market. However, their prices—about $900 for the frame or $2000 for a complete bicycle—will likely limit their acceptance.

New developments are also taking place in the way power is transmitted from the rider to the wheels. Perhaps the most radical innovation is the Powercam, a device placed between the pedal crank and the chainwheel—the toothed wheel that carries the bicycle chain. The Powercam allows limited back and forth movement of the crank independently of the chainwheel, causing the crank to lead the chainwheel on the downstroke, or powerstroke, and lag it on the return stroke. Developed by NASA engineer Larry Brown, the Powercam is marketed by Powercam-Houdaille Industries (Fort Worth, Tex.).

The motion of the Powercam is said to more closely follow the natural movements of the legs than the evenly spinning motion necessitated by conventional pedal assemblies. Tests of the device conducted by the U.S. Olympic team, the University of Iowa, and the Institute for Aerobics Research have indicated that riders can maintain lower pulse and respiration rates for equivalent outputs of mechanical energy than when riding conventional bicycles. However, experts differ on the merits of the Powercam. "We found it to be unreliable," says Melton, "It's like a sewing machine—any dirt in the mechanism and it won't work." Nevertheless, Powercams have been successfully used in numerous long-distance racing events, especially triathlons, though some riders claim that the device can be a hindrance in short-distance races.

Nonetheless, the power gain and improved energy transfer possible with the Powercam has already encouraged imitators. Shimano of Japan, the giant bicycle-component manufacturer, now



Houdaille's Powercam (bottom) has a small cam fixed to the bike frame. While the chainwheel moves at a constant rate, the pedal cranks speed up and slow down as the oscillator revolves around the cam and its gears engage the inside teeth of the chainwheel. The net effect is to provide larger gearing on the downstroke without increasing leg force. A similar effect is produced with the Japanese Shimano Biopace chainwheel (top). Its unusual ellipsoid shape results in a larger radius when the crank is vertical and a smaller radius with the crank horizontal.

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markets the Biopace, a semi-elliptical chainwheel that duplicates some of the power gain of the Powercam without infringing on the patent. The pointed section of the ellipse faces forward on the downstroke, while the flatter section comes forward on the upstroke. The effect is to increase power on the downstroke and speed on the upstroke. Unlike the Powercam, the Biopace requires no additional mechanical parts or extra lubrication and can be combined with an ordinary chainwheel in a two-ring crank assembly.

Shimano is one of the leading producers of racing derailleur gear sets, the type where the chain is shifted on a series of graduated sprockets on the rear wheel hub. The company recently introduced a derailleur gear with click-stop positioning for the gearshift lever. The fixed positions for each gear allow positive shifting and so eliminate the missed shifts that plague conventional derailleurs. While this may seem a simple development, it requires an extremely precise derailleur gear assembly, made possible by Shimano's extensive use of computer-aided design. Shimano's new Dura Ace gear is threatening the dominance of the Italian Campagnolo derailleurs, long the standard for performance bikes. Shimano is also rumored to be planning other refinements, including the use of lightweight carbon-fiber composites for many of its gear system parts.

Seats—usually unyielding leather saddles—have also been receiving attention lately. New designs for racing bicycles are attempting to increase rider comfort. Avocet (Menlo Park, Cal.) recently patented a saddle with two small foam cushions placed where the rider's pelvic bones rest on the seat. The saddle also has a plastic frame that varies in thickness so the saddle will flex more in response to road bumps. Other innovations in seat design have come from two smaller companies, Spenco (Waco, Tex.) and Hydro-Seat (Rochester, Minn.). Spenco's seat is lined with vibration-damping Sorbothane, while the Hydro-Seat contains a water-filled rubber cushion that is rather like a tiny waterbed. Both saddles are said to reduce road shocks and increase rider comfort dramatically. □

Daniel Sweeney is a freelance writer based in Los Angeles.

TOOLS FOR MANIPULATING SYMBOLS

Scientific word processing can be a character-building experience

Business word-processing programs have pretty much settled on a collection of mostly commonplace features; all such programs use a standard character set in a single size, and at most offer only a few spacing options, based on the features of daisy-wheel printers. The screen and printer essentially behave as if they were typewriters.

This arrangement works adequately for business correspondence and memos, whose layouts follow patterns established a century ago. For many users, however, the traditional typewriter model with its fixed set of characters isn't enough. Scientists and other professionals in fields as diverse as pharmacy and linguistics need to use special symbols.

A scientific word-processing system should be able to create and modify characters, as well as change their size, since no fixed set of characters can satisfy all needs. The system should not only drive ordinary computer printers but also drive typesetting machines, without further changes to the document. Such a system requires careful coordination between hardware and software, so that the printed results match the screen display closely.

Software developers have tried to meet these challenges in many different ways; the result is much greater variety among scientific word processors than among conventional word processors.

Editing strategy. Scientific word processors fall into roughly three categories: mark-up languages, mark-up extensions, and what-you-see-is-what-you-get (WYSIWYG); there are, however, many variants. Mark-up language programs aren't really word processors at all. Instead, you use an ordinary word processor to add a special set of coded commands (using standard ASCII characters) along with the normal text. The mark-up program takes the file and translates the commands into the form required by the printer to generate and position special symbols. Many people have used mark-up languages to drive traditional typewriting equipment; the dot commands of WordStar are a simple mark-up language.

Mark-up languages can be flexible and powerful, but they are very hard to learn and unsuited to occasional use. You cannot see any results until you send the file for printing, although some new programs have an optional preview mode that "prints" on a graphics display. The preview screen is not interactive; to make changes you must go back to the editor, change the command codes, and print everything again to see the results. For long documents, this process can be painfully slow.

A mark-up language can drive a variety of printers and typesetters, but installation can be complex and may require a consultant. Some languages are available for a range of computers from micros to mainframes, so a file can be transferred intact with formatting. The American Mathematical Society encourages authors submitting papers to its journals to use a special format based on TeX; papers submitted in this form can be set in type without extensive reworking.

A mark-up extension program is an add-on to an existing word processor—such as WordStar—to add limited scientific-character capabilities. Mark-up extension programs are suitable for occasional use if you already own the primary word processor. They can be fairly easy to learn, but they are also much less powerful and generally work only with older word processors that lack modern features. Many conventional word processors allow for subscripts and superscripts but not simultaneously—for example they cannot produce $\mathbf{X}_i^2$.

WYSIWYG word processors show you the equations and other text directly on screen. You work with the text interactively, so you see changes immediately. There are many variants: WYSIAWYG means "what you see is *almost* what you get." WYSIWYG/typewriter means the display follows a typewriter model with fixed character sizes and spacing. And WYSIWYG/graphics means that the display is graphics-driven and includes variable character sizes.

WYSIWYG programs are much easier to learn and use than the mark-up languages, but the ability to handle fonts introduces many new issues.

Fonts. Traditional text-mode computers (such as the IBM PC with IBM's Monochrome Graphics Adapter) cannot display symbols or graphics; they are limited to the single character set in a fixed size that is installed in a read-only memory (ROM) chip. Although the IBM monochrome adapter has a 256-character ROM, compared with ASCII's 96, the additional characters are for foreign languages and for drawing boxes on screen; they are not useful for scientific applications. Some vendors supply special ROMs with scientific characters loaded, but such ROMs are still restricted to a fixed character set in a single size.

A graphics, or bit-mapped, display can show any character in any size under software control, subject to limitations in the display resolution and the ability of the printer to recreate the character on paper. Many programs that use a graphics display, however, do not let the user create new characters or change sizes.

On the IBM PC, the IBM Color Graphics Display Adapter shows bit-mapped images, but its resolution is too coarse for intensive work. The best choice now is the Hercules graphics adapter or an exact equivalent; you should choose software that supports this card. In the future, IBM's Enhanced Graphics Adapter will probably become an alternative as it gains more software support.

Any special symbols defined in software on the IBM PC are available to the scientific word processor only; you cannot use the symbols in a spreadsheet or database.

Most Apple Macintosh programs use

by Cary Lu

Scientific word-processing styles

Graphics model	Laser printer output	Typewriter model	Mark-up language
$\frac{\Gamma_2 + y^2}{k + 1}$	$\frac{\Gamma_2 + y^2}{k + 1}$	$\frac{\Gamma 2+y^2}{k+1}$	`$$\Gamma_{\!2}+y^\over k+1$$`

Scientific word processors must cope with many more variations than conventional word processors. A what-you-see-is-what-you-get program following a graphics model would display symbols on screen complete with variable-size characters and positioning (left). The screen display, aside from resolution limitations, corresponds closely to output from a laser printer (second from left) or typesetter. Typewriter-model programs can display and print only fixed-size characters with limited positioning (center). A mark-up language program (right) does not show the symbols during editing; instead you must learn a new language to describe what you want (the example is written in TeX). You can see the results only after processing.

interchangeable fonts and scientific symbol fonts available from many sources. With the FONTastic font editor from Altsys, you can create and change characters and even add characters designed in MacPaint. In the future, programs running under Microsoft Windows or Digital Research's GEM could bring Mac-like operations to the IBM PC.

Character size and positioning. The noninteractive mark-up languages force you to work blind until you print the results.

WYSIWYG/typewriter programs can position characters horizontally only by a fixed space and vertically by a half space (and occasionally by a smaller space). The results look like typewritten manuscripts. Although its capabilities are limited, typewriter positioning with fixed sizes is simple.

More modern graphics-based programs may permit arbitrary positions and sizes, but many also include the option of typewriter-style fixed sizes for quick jobs. The programs that offer variable character sizes confront many problems in managing character position; the most advanced forthcoming programs will let you put anything anywhere with a mouse or cursor keys and magnify the screen image for more accurate placement. A nonprinting grid will guide your placements.

On the IBM PC, "variable" size usually means a few discrete sizes, such as 9-, 12-, and 18-point type. On the Macintosh, continuously variable type sizes from 4- to 127-point are available with some programs.

File formats. All word processors save both text and formatting information such as line spacing, margins, and so on, in disk files. Although formatting information is often hard to convert, most standard word processors can read and write standard ASCII text files and can thus exchange text information (HIGH TECHNOLOGY, Sept. 1985, p. 54). There are no standard coding schemes for special characters, so no scientific word processor can exchange complete, formatted files with any other word processor. However, most scientific word processors can read ASCII files produced by other word processors and can create ASCII disk files by stripping out all the special characters and formatting information before writing on the disk. Mark-up languages use only standard ASCII characters, so the files generated for them can be moved readily to any word processor.

Printers. Daisywheel printers have been the traditional choice for word processing. For scientific applications, daisywheel printers are hardly ideal, since standard daisywheels and thimbles contain only 96–128 characters. (You can, however, choose the symbols, and specialty companies can modify daisywheels by changing petals.) To get more characters, you must change wheels—a severe inconvenience. Some users resort to printers with two print heads, putting an ASCII wheel on one head and a symbol wheel on the other. The best daisywheel is simply the one with the most characters, so the 192-character daisywheel on the Diablo 630 ECS printer takes the prize. Although the additional characters help a great deal, they cannot meet the needs of every user, and the character sizes remain fixed.

A dot matrix printer, on the other hand, can print any combination of dots and thus any character in any size. This flexibility generally outweighs its poor print quality relative to that of a daisywheel. To exploit this flexibility, however, requires a powerful word-processing program that can take full advantage of the printer's features.

Display–printer correspondence. Mark-up languages and other programs that run in text mode make no effort to match the screen and printer. For instance, you must remember that "/beta" or "^B" means "β."

The main problem facing the graphics-based programs is getting the screen display and printer to match despite an often considerable difference in capabilities. With most IBM PC programs able to handle bit-mapped characters, the screen and the printer use separate bit maps. The WYSIWYG/typewriter programs are limited to a single, fixed character size, so although their matching problems are relatively simple, they cannot drive a typesetter adequately. The programs that let you design your own characters often make you do it twice—once for the screen and again for the printer.

Defining the bit maps a pixel at a time works adequately for the common very-low-resolution dot matrix printers with 70–150 dots per inch. With medium-resolution laser printers (240–500 dots per inch), however, there are too many dots: Since only the most patient and skillful users can create satisfactory characters, most users must rely on existing font libraries and on their own lower-resolution creations for any missing symbols. The lower-cost laser printers such as the Hewlett-Packard LaserJet and LaserJet Plus are limited to fixed-size fonts installed via a ROM cartridge. If you install a symbol font on the printer, you must then load a separate font for the screen as well and possibly wind up with size mismatches.

On the Macintosh, the tight correspondence between screen and dot matrix printer makes life much easier, since both use the same bit map. For higher-quality output with LaserWriter or typesetters equipped with

Scientific word-processing software

A good scientific word processor with WYSIWYG (what you see is what you get) graphics is not yet available for microcomputers. The Apple Macintosh, Digital Research GEM, and Microsoft Windows show how such a program could work, but the word processors available for these systems do not include essential features necessary for scientific applications.

The first scientific word processor for the Macintosh, **MacAuthor** from England, was not finished as this article was being written. It includes such features as stacking subscripts and superscripts on the same character and the ability to create characters within the program. Because it works with the Macintosh operational style, you can use MacAuthor and another Macintosh word processor at the same time with only minor discomfort.

On the IBM PC, the self-contained scientific word processors follow different paths. Unfortunately, all of them are complicated and hard to learn; none are likely to convince you to abandon a conventional word processor. But the alternative of using a conventional word processor and a scientific one in parallel creates many problems; you have to put up with two incompatible file formats and totally different working styles. These scientific word processors are not suitable for occasional use; you must take the time to master them and maintain your skills through regular use. Organizations that generate a lot of scientific manuscripts should probably designate a scientific word processing operator to handle all manuscripts.

Several WYSIAWYG (what you see is *almost* what you get) typewriter programs are available for the IBM PC. **Volkswriter Scientific** is a hybrid; it uses typewriter model positioning vertically but has proportional spacing with microjustification (positioning in small increments) horizontally. Volkswriter Scientific offers several character sizes, although you cannot create new characters. It is page-oriented, meaning that you must switch from page to page instead of scrolling through a document. The program is suitable only for preparing a final printed copy, as it lacks such common word-processing functions as search and replace. The program is unrelated to the standard Volkswriter word processor; it can read but cannot create ASCII files. Version 1.0 does not support the Hercules board.

Three WYSIAWYG/typewriter programs also include common word-processing features; they can read and write ASCII files as well as their own formats. All permit you to create new characters for the screen and printer, and all support the Hercules board. They use fixed-size, monospaced characters, and position by the character horizontally and by the half-line vertically. A few large symbols such as integral signs can be created out of smaller components. All these programs have dense, hard-to-understand manuals made worse by their non-MS-DOS origins, and have trouble with the simplest operation—even moving the cursor about the screen. They are strongly mode-driven; for example, the keyboard functions change depending on whether you are in command mode or edit mode, and you must often go through many unnecessary steps to perform routine functions. The programs can print italics and boldface with the common dot matrix printers as well as drive daisywheel models.

T3 from TCI Software closely follows a technical typewriter model; it manages many functions through a complex set of menus. Such simple features as repeating cursor keys are left out. T3 comes with the greatest number of predefined characters, including a Cyrillic alphabet along with math, Greek, and chemical symbols. The patient user will be rewarded for carefully going through the long, thorough tutorial. T3 includes keyboard macros but does not have mail-merge.

BRIT Scientex offers fairly crisp operation, which is marred by its inability to move the cursor vertically past paragraph breaks. Keyboard assignments change from mode to mode; for instance, the F1 key reads a file in one mode while F5 reads a file in another mode. Scientex positions characters to one-sixth of a line vertically and can perform mail-merges with commands embedded in the text. It comes with a useful set of instructional files on disk; ignore the poorly produced manual for as long as you can. Scientex does not include keyboard macros but will work with separate keyboard enhancer programs.

Spellbinder Scientific is derived from the veteran Spellbinder word processor from the early days of CP/M. It is strongly mode-driven, even for cursor movements. The particularly complete macro-command function is virtually a programming language; it provides mail-merge and many other functions such as adding a column of numbers. Spellbinder is particularly suited to the sophisticated and determined user who can take full advantage of its many options.

Mark-up languages are harder to use. **SuperScript** is a memory-resident program that adds scientific functions to an existing word processor by operating in memory at the same time. You type in a mark-up code using your standard word processor and then select SuperScript's display mode. This mode freezes the word processor and displays the results of the coding on a split screen, complete with font changes and sizes. The graphics display is not interactive, and you cannot see the symbols and the rest of the text at the same time. When the document is complete, SuperScript intercepts the normal printing commands and can display both text and equations on the screen (again, noninteractively) or send the composite results to the printer.

The best-established mark-up language is **TeX**, available for the IBM PC and the Mac as well as many UNIX systems and large computers. You use a standard word processor to create the TeX files; the TeX formatter then translates the files for the printer or for preview on a screen. On the IBM PC, both Addison-Wesley and Personal TeX offer full implementations that work well. TeX is independent of output devices; the same TeX code can drive anything from video displays and dot matrix printers to laser printers and typesetters. TeX is noninteractive and a challenge to learn and use. Future versions could adopt better interfaces, including a menu-driven style that will hide complex details from the user. Some organizations have created templates in TeX; if your requirements fit the template, you need only make modest changes without having to create the entire edifice from scratch.

PostScript, each font comes in size-coordinated forms for screens, laser printers, and typesetters. Each device renders the information at its own resolution, yet all versions correspond closely and all devices can produce any character in any size.

Graphics. Many scientific symbols cannot be created satisfactorily with any text font. Chemical structures can be built up from a "stick" font, a set of lines at different angles, but only through an extremely tedious and exacting process. A few scientific word processors for the IBM PC include rudimentary drawing capabilities, but these can usually just barely cope with a simple organizational chart, and none come close to the capabilities of separate, mouse-driven drawing and painting programs. What's more, the early graphics programs on the IBM PC have a severe limitation: You cannot combine the graphics with a word-processing document.

On the Macintosh, the graphics tools are powerful; you can create or buy a library of chemical structures for quick recall and modification as required, and then place the results into any word-processing program.

All these complications leave scientific word processing a confusing field. No one program can handle all tasks well; concentrating on the symbol manipulation features often seems to result in weak underlying word processing.

Only steady, intensive users should consider mark-up languages, for such programs are difficult and tedious to learn. Yet only mark-up languages—in the hands of a skilled operator—currently offer nearly complete printing features that meet typographic standards, although they cannot cope with drawings. The available WYSIWYG programs on the IBM PC are not particularly impressive or powerful, but they are much less painful to learn and use than the mark-up languages.

At the moment, none of the scientific word-processing programs on the IBM PC are particularly good for ordinary word processing. This weakness will force many users to adopt a scientific package only as a second word processor. Running two word processors simultaneously creates file incompatibility and requires users to stay on their toes, since the program styles inevitably clash. □

Cary Lu is microcomputer editor of HIGH TECHNOLOGY.

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THE PBX GETS PDQ

Faster in-house phone systems offer fancy voice/data features, but is there a market?

Vendors of computer hardware and software like to distinguish between new and old systems by decreeing that a new "generation" of products has arrived. Suppliers of private branch exchange (PBX) systems—intracompany networks that link telephones and, increasingly, computers and data terminals—are no different. Of late, several vendors have been marketing their systems as "fourth-generation" PBXs, which, by implication, supersede their predecessors.

The earliest PBXs established physical paths between callers via a central matrix of operator-run "cordboards." During the '70s, second-generation systems introduced software that directed calls automatically, thus replacing operators and electromechanical switches. These systems also began carrying limited amounts of data traffic as well as voice traffic. Since the early '80s, third-generation PBXs have routinely carried both voice and data transmissions, without "blocking" the voice calls, a second-generation phenomenon that often gave callers a busy signal rather than immediate system access.

Fourth-generation systems base their claims of distinction on the way they handle data communications. Anticipating a boom in such transmissions, PBX vendors have begun to integrate local-area networks (LANs) into their architectures. While most third-generation PBXs transmit at 56–64 kilobits per second (kbps), cable-based LANs carry virtual rivers of data at speeds that typically range from 5 to 50 megabits per second (Mbps). Fourth-generation PBXs use various methods that attempt to reduce this disparity.

by Mary Karr

The focus on increased data rates, however, sidesteps the fact that most PBX buyers still use the systems mainly for voice communications. The third generation was earmarked by money-saving voice features such as call accounting (for intracompany cost control) and automatic route selection (to exploit cheaper long-distance services). Although the data-oriented fourth-generation systems have retained these voice features and added some new ones, the innovations are unlikely to have the same impact as those of the previous generations.

Digital switching is another capability that debuted in the third generation and remains for the fourth. Second-generation systems used modems to translate digital bit streams from terminals into analog waves resembling speech signals. Reversing the process, more advanced systems digitize analog voice signals so they can travel along the PBX's digital "bus" (an internal information highway) interchangeably with computer data. Digital signals can be stripped of noise and easily regenerated, resulting in fewer errors than with analog transmissions. By becoming digital, third-generation PBXs (and their fourth-generation progeny) could also exploit economies available from very large-scale integration (VLSI) components, permitting more PBX intelligence at a lower cost.

PBX intelligence has gradually been migrating from a central source toward the user.

A much heralded technology driving both digital generations is the Integrated Services Digital Network (ISDN). An international access standard not yet finalized, ISDN will exploit long-distance digital T-carrier links, which carry data and voice traffic at 1.544 Mbps (HIGH TECHNOLOGY, Sept. 1985, p. 20). With ISDN, a data call that now requires a special leased-line arrangement could cost the same as a voice call and be placed as easily.

But digital PBXs of any vintage could provide the office gateway to the ISDN promised land, or simply make available many of the features that are important to many users. As a result, "if computer data calls typically last a few minutes and total less than a few hours every day, any digital PBX can handle your needs," concludes Martin Pyykkonen, a senior consultant with Arthur D. Little (Cambridge, Mass.).

Still, fourth-generation PBXs do offer managers some new voice-handling capabilities, including integrated voice-and-text mail. This application lets managers annotate files or memos with voice notes, circulating the spoken comments with the document. Storing digitized voice for such applications can require massive amounts of memory, and the applications have recently become feasible largely because of lower memory costs and improved data-handling methods. Voice-compression software can reduce digitized voice to one-quarter its original size. By stripping out silences in a conversation, PBX vendors can achieve a further 20% reduction, making voice storage much more economical.

The new PBXs also incorporate dramatic changes in architecture, and these can be important to users with substantial data traffic. Perhaps the greatest architectural shift involves the distribution of intelligence away from a central source. In 1879, an operator at a cordboard provided centralized PBX intelligence when he or she remembered the name of everyone within the company. This configuration continued until very recently, with phone wires forming a "star" topology with a software-based intelligent switch.

Yet this centralized approach has its problems. Expanding the system can usually occur only in large steps, provided by the acquisition of a more powerful, and more expensive, central PBX switch; the new switch may increase capacity by thousands of lines, when only a hundred or so are needed. In addition, the failure of the central

node could sever all company communications.

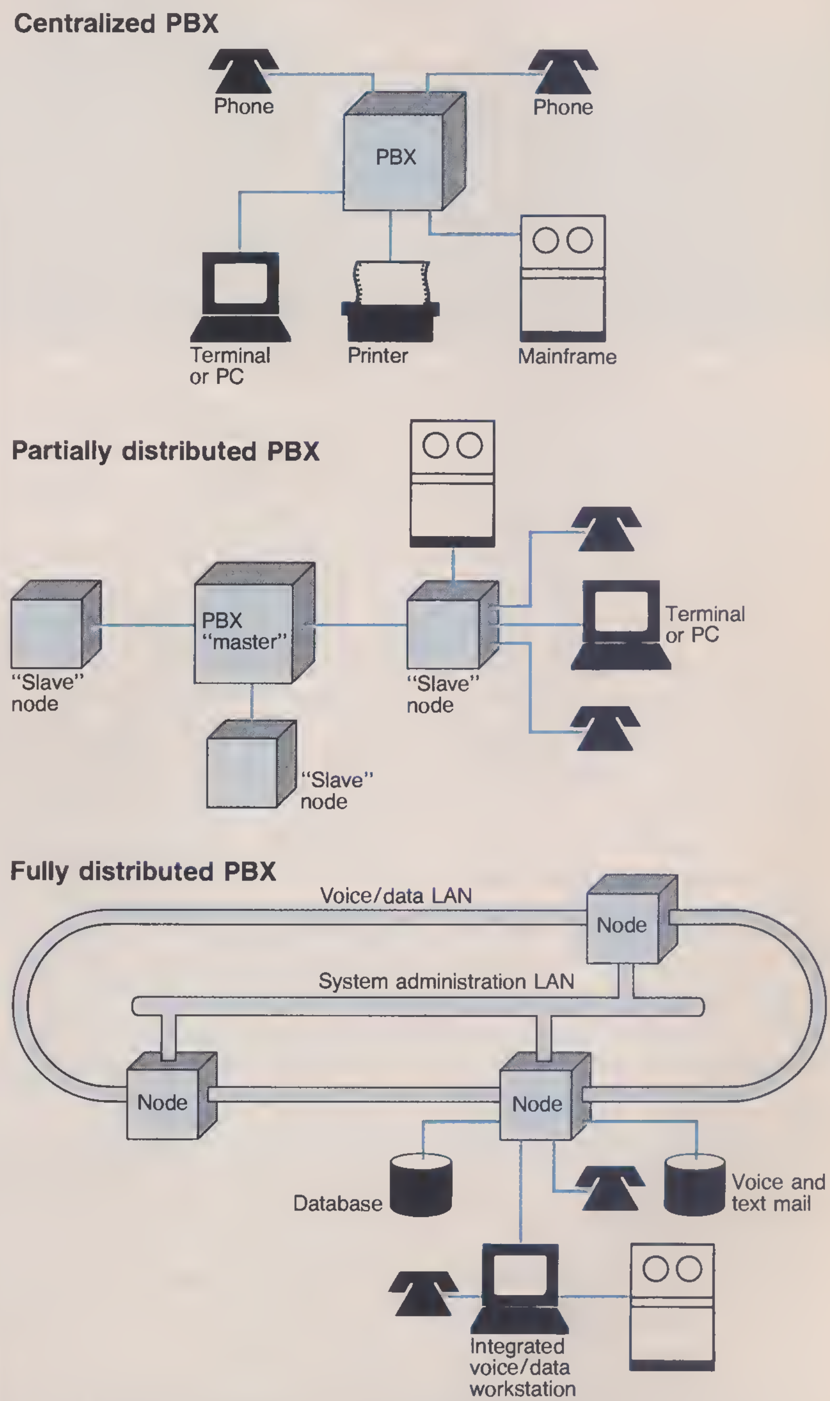
For these reasons, and because of new economies made possible by VLSI technology, PBX intelligence has gradually been migrating from a central source toward the user. Some partially distributed systems like the IBX from Intecom (Allen, Tex.) still use a central computer (actually two are supplied for redundancy) as a traffic-cop "master" that sends orders to distributed "slave" modules. These, in turn, perform most of the voice- and data-handling functions and provide increased modularity for easier system growth.

Other systems, such as the Rose PBX from CXC (Irvine, Cal.), eliminate the central computer entirely. Such fully distributed systems employ independent nodes that are immune to each other's failures. Each Rose node controls 192 communications ports and contains some information about the other nodes, for purposes of communication. Because there is no centralized, shared memory about each voice or data device on the system, the complexity of communications between nodes is increased. This drives up software costs, which already make up about 80% of typical PBX expenses.

One function that has migrated from the central PBX in all advanced systems is the voice digitization process. Coder-decoder (codec) chips in the telephone handset employ pulse-code modulation (PCM) to immediately translate the voice wave into a bit stream. This means voice and data can share the same desktop line card and wire as well as the same PBX port; previously, separate cards and lines for voice and data were required. (With PCM, the codec chip samples voice signals 8000 times per second. Each sample is then encoded with an 8-bit binary number describing that particular slice of speech wave. That's why a voice call requires a 64-kbps channel—8000 samples × 8 bits = 64,000 bps.)

In most advanced PBXs, PCM works in tandem with time-division multiplexing (TDM), a technique that combines, or interleaves, multiple voice signals and some data signals on single channels. TDM assigns a time slot on a PBX internal bus to each device. Within the PBX matrix switch, the incoming signal gets shifted to the appropriate outgoing channel to reach the proper destination device. Voice and data signals fragmented by the TDM interleaving are reconstituted at the receiving terminals.

TDM still handles most voice traffic in fourth-generation systems, but a new technique called "burst-mode switching" transmits data more efficiently. People placing voice calls demand a connection with no apparent delays. By contrast, data can often wait for transmission. Burst-mode switching stores, or buffers, data at the workstation, placing the data in discrete packets, which also contain control information such as the receiver's address. The buffered packets are transmitted in bursts through the PBX



The computer-based intelligence of PBX systems has been gradually moving from a single, central switch to distribution throughout the network. Partially distributed systems spread some of the work among "slave" processors but retain a central controlling "master." Fully distributed PBXs employ intelligent nodes that totally support the devices linked directly to them, and have no central control point.

DAVE HANNUM

during pauses or dead time, thus exploiting PBX capacity that would otherwise remain idle.

"Dynamic bandwidth allocation" is another feature of fourth-generation PBXs that seeks to increase data-handling efficiency. With this method, a data device that must send a huge file can request and receive as much bandwidth as is needed from the PBX's bus, up to its maximum capacity of many megabits. Though allocation methods differ among systems, this ability to alter the available bandwidth means the PBX can adapt to fluctuating user needs. As a result, a user who occasionally sends large files can do so without requesting a permanent system reconfiguration that allocates infrequently used PBX capacity.

While all these voice- and data-handling features represent important PBX advances, the major shift in the fourth generation is the integration of high-speed LAN capability within PBXs. Changes in office computing habits have fueled this trend. Five years ago, for instance, most computer applications involved "transaction processing," which required relatively slow speeds compared with the more sophisticated and higher-demand applications of today. Transaction processing requires direct user interaction with the system; even the relatively slow transmission speed of 64 kbps can more than keep up with a person typing information into the system or reading it on a screen.

The distribution of intelligent computing devices throughout offices is shifting the application mix away from such simple transactions. As the affordability of PC memory increases, for example, so does the need to rapidly carry more data to and from the desktop. Someone loading a 256-kilobit file at 9600 bps would wait only about 27 seconds. But if the file size reached 5 megabits, loading would take about nine minutes, an unacceptable delay.

Many of the newer bandwidth-hogging applications, such as computer-aided design and engineering, involve graphics. These and other evolving applications such as full-motion video—which requires 448-kbps transmission—threaten to overflow the third-generation PBX pipelines. Thus the vendors' recent emphasis on speed.

What's not clear, however, is how many companies currently require such high-speed transmissions. According to ITT, 90% of all data transmission occurs at or below 9600 bps. And some question the usefulness of the newer applications that require higher data rates. "How much would you pay to see my lips move?" asks Lee Goeller, a consultant in Haddenfield, N.J., when discussing the value of video teleconferencing. Others believe the need for LAN data rates is real and growing, however. A recent survey of telecommunications managers at major corporations conducted by Temple, Barker and Sloane (Lexington, Mass.) indicates that voice transmissions are expected to grow at an annual rate of only 6–10%. "But they double or triple that growth rate when estimating for data," reports Jack Boyles, an associate with the consulting firm.

In most third-generation environments, the PBX coexisted with the LAN, which carried high-speed data while the PBX handled voice and low-speed data. But this required the installation of separate LAN wiring and connectors to desks already reached by phone wire. Attempts to combine all traffic over a single wiring system faced a dilemma: The cost of high-capacity LAN coaxial cable and connectors was too high, and inexpensive "quad," or twisted-pair, PBX cable was of limited capacity.

Standard twisted-pair phone wire averages $35–$40 per 1000 feet, while similar lengths of the coaxial cable used in many LANs range from about $200 to almost $1000 for the popular Ethernet LAN. And because coaxial cable is heavier than quad wire, installation costs can double. Finally, wall connectors, which cost about $3 for standard telephone wire, cost about $6 for coaxial cable—a difference that can add up in networks with hundreds or thousands of connections. In addition, Ethernet nodes each require a special transceiver that typically costs just under $300.

Although inexpensive phone-wire tentacles offer the advantage of already reaching every desktop, until recently they've been limited to 64-kbps rates. But new PBX technology pushes data from terminals and PCs at much higher speeds. In particular, Northern Telecom's recently announced Meridian SL-1 product line provides 2.5 Mbps from the workstation over standard phone wire within 2000 feet of the PBX. That's more than twice the capacity available from competitors such as Intecom, which have recently begun to tout 1-Mbps rates.

Northern Telecom derives this increased capacity from proprietary chip technology that does various types of signal processing such as noise filtering. Certain noise-filtering techniques are very common, such as radio-frequency (RF) filtering. In fact, the Federal Communications Commission requires PBX vendors to filter the frequencies between 30 and 300 megahertz (MHz). This filtering prevents radio waves and PBX signals from interfering with each other.

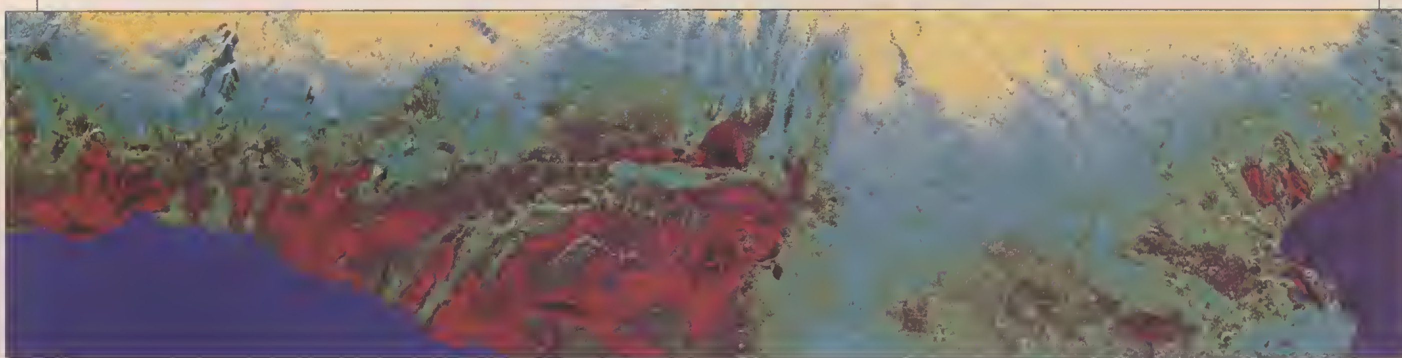
The tougher problem involves the interference between PBX signals within the same system. Phone wires, transmitters, and receivers close to one another can cause "crosstalk," which pollutes the transmission signal with noise that, in the 0- to 2.56-MHz range, can closely resemble the signal itself. Distinguishing and eliminating the bad information is an extremely difficult task; Northern Telecom's chip, using proprietary methods, reportedly achieves this filtering and thus permits the high-speed transmission of clean data.

Rather than attempting to boost the data rate carried by twisted-pair wiring, some PBX vendors are integrating coaxial-cable data paths directly into their networks. CXC's Rose, for example, actually incorporates two cable-based LANs. One, a 50-Mbps pathway that serves as the PBX's internal bus, consists of a 33-Mbps, TDM-switched pipeline that carries voice and data, and a 16-Mbps channel that is reserved for future applications. The second LAN employs the popular 10-Mbps Ethernet standard. CXC claims that the separate Ethernet system will eventually be replaced by the 16-Mbps channel on the first LAN.

While the CXC system has a high-speed central data path, however, individual phones and terminals are connected to the 33-Mbps pipeline via 1.92-kbps twisted-pair links. The reason is that it's still not economically feasible to bring LAN-level data rates to every office phone. Because of this cost barrier, PBXs that are moving to envelop the LAN function have yet to prove that they offer a viable alternative to separate, but symbiotic, LANs and PBXs. Such proof may be forthcoming if two trends continue: the steady drop in high-speed cabling and component prices, and the proliferation of intelligent desktop devices that require high data rates. □

Mary Karr is a freelance writer and consultant specializing in communications.

RADARS IN SPACE



JET PROPULSION LAB

Space-based imaging radar systems can pierce darkness and clouds to map the earth's surface. This color-coded shuttle radar image of Hawaii, for example, reveals four different kinds of ground cover: smooth ash (red), smooth lava (light green), rough lava (dark green), and vegetation (blue). The high-resolution (30-meter) system detected Hilo Airport's runways (far right) from 200 miles up.

NASA steps up mapping of earth resources

It has long been suggested that radar would offer important advantages as a space-based earth-sensing technology. In contrast to optical systems, which work only in the daytime, radar would acquire images of the earth at night and through dense cloud cover. Until recently, radar attracted little attention in the remote-sensing community, simply because optical systems have been able to meet the imaging needs of most users.

Now, however, preliminary studies of images produced by a Space Shuttle–borne radar system are sparking renewed interest in this technology. The studies indicate that radar could detect clues to mineralogical, hydrological, and vegetative resources that are hidden from optical systems even in clear weather. For example, shuttle radar images recently revealed ancient riverbeds that the sands of the Sahara Desert had hitherto concealed from satellites. The studies also show that some types of crops can be more easily differentiated in radar images than in optical images.

NASA has consequently decided to pursue its shuttle radar program through the end of the decade, and it plans to orbit a permanent radar facility in the next decade. If the plan is carried to completion, earth resource hunters could soon have an important new prospecting tool.

by Robert G. Nichols

This is not to imply that radar should replace optical sensing systems like those on the United States' Landsat or France's new SPOT earth observation satellites. Far from competing with each other, the two technologies are complementary: They provide different types of information about the same areas. Optical sensors can produce images with much finer resolution, for example, while radar is much more sensitive to surface roughness and soil moisture.

The current Shuttle Imaging Radar (SIR) program involves orbiting increasingly sophisticated versions of a so-called synthetic-aperture radar (SAR) system that was developed for NASA by the Jet Propulsion Laboratory (JPL) in Pasadena, Cal. What differentiates a synthetic-aperture radar from a conventional radar is digital signal processing, according to John Curlander, supervisor of JPL's systems and data processing group. Like a conventional radar, JPL's SAR bounces high-frequency pulses off the earth's surface to form an image. But instead of displaying them directly on a cathode-ray tube, the SAR system first digitizes the echoes and then uses a computer to extract features that are smaller than the width of the radar's beam. The result is images having a resolution between 15 and 50 meters. To produce an equivalent image without signal processing would require an antenna with a very large aperture—too large for the Space Shuttle.

A space-borne synthetic-aperture radar was first carried into orbit in 1978 aboard Seasat, a remote-sensing satellite that used a battery of instruments to study the oceans. Though only a fraction of Seasat's images were of land surfaces, the quality of those images convinced scientists that SAR would be useful for imaging geological formations and vegetation from space. As a result, NASA decided to use its new shuttle to orbit three more radar imaging systems.

The first Shuttle Imaging Radar, SIR-A, was carried into space aboard the *Columbia* in November 1981. Like SEASAT, SIR-A transmitted and received horizontally polarized signals at a frequency of 1.28 gigahertz. The main difference between SEASAT and SIR-A was the angle at which the radar signals hit the earth. SEASAT's antenna was angled so that the beam hit the target area at 23° from local vertical (0° being straight down), while SIR-A's antenna was oriented so the beam hit the ground at the shallower angle of 47°. By comparing the images produced by the two systems, scientists determined that steeper angles were better for identifying vertical formations like hills and valleys and that shallower angles were better for providing information about surface texture.

Although SIR-A's investigations covered several disciplines, its main focus

was geological. Images of ancient riverbeds beneath the Sahara were probably the most unexpected discovery: To the investigators' surprise, SAR could "see" through the dry desert sands and produce images of the topography several feet below the surface. Such capability holds great promise for archaeological research as well as for efforts to find groundwater in arid regions.

SIR-B, the second Shuttle Imaging Radar, featured multiple-angle imaging. Carried into orbit by the *Challenger* in October 1984, it used a motor to mechanically rotate its antenna to vary the radar's "look angles" between 15° and 60°. On different orbital paths SAR could image the same area at a variety of angles. SIR-B showed that multiple-angle imaging is better at characterizing surface features, such as the weathering of rock, than a system with a single look angle.

Researchers had more ambitious plans for SIR-B than for its predecessor. SIR-B investigations covered five disciplines: plant science, oceanography, hydrology, cartography, and geology.

Plant science studies focused on areas "intensely managed by the forest service and paper companies, because very good records of the areas were available for comparison," explains Martin Ruzek, science coordinator for the SIR program. The results caused Ruzek to speculate that SAR images may be better than optical images for determining the age of a stand of trees. To an optical system, the color and leaf structure of young trees are similar to those of older trees. However, SAR may be able to distinguish between new and old growth by sensing differences in the canopy texture.

Other studies included mapping sections of the ocean floor, discriminating between different types of rock, testing SAR's ability to penetrate sand, and detecting groundwater.

Despite these ambitious plans, however, SIR-B encountered two problems that severely curtailed its investigations. First, data could not be transmitted to a communications satellite and relayed to ground stations in real time, because the *Challenger*'s Ku-band antenna jammed. However, SIR-B had a tape system that could store the digitized data. After SIR-B imaged a series of targets, the *Challenger*'s crew rotated the entire spacecraft so that the antenna pointed at the communications satellite. By repeating this procedure, they managed to transmit eight hours' worth of data for processing, but this was far less than the 50 hours that project scientists had anticipated. It translated into 6 million square miles of ground coverage instead of 18 million.

The second problem was with SIR-B itself. A partial short in a cable between the antenna and the transmitter reduced SIR-B's transmission signal strength by 98%. To compensate, the gain on the return signal was boosted as much as possible, with mixed results.

In spite of these problems, SIR-B generated enough images to keep the 43 SIR-B investigators in all five disciplines busy for months. To make up for the lost data, NASA agreed to refly SIR-B in the spring of 1987. This mission will be a polar flight allowing SIR-B to image the higher latitudes that were beyond the horizon during the 1984 mission. SIR-B may even image the North and South Poles, a first for an earth observation system.

The third Shuttle Imaging Radar—SIR-C—will be orbited twice, in 1989 and 1990. Like SIR-B, it will be able to vary the radar's incidence angle. But instead of a motor to tilt the antenna, SIR-C will direct the beam by adjusting phase shifters on the antenna. The beam will sweep between 20° and 60° without the radar moving.

A major goal of SIR-C is to combine multiple-angle imaging with multiple-frequency imaging. While the previous orbiting SARs could transmit only at 1.28 gigahertz, SIR-C will transmit at 1.28, 5.8, and 9.6 gH. Researchers want to determine if some surface features appear brighter at one frequency than at another, as an aid to identification.

Imaging radar systems can penetrate sand as well as darkness and clouds. A shuttle radar image (inset) of the Sahara Desert shows ancient river beds concealed by surface sand in corresponding Landsat images (background).

In addition, SIR-C will employ multiple polarization techniques, combining the vertical and horizontal components of the return echo to further enhance images of geological formations and vegetation. Earlier SARs produced images by using only the horizontal component of the return echo. Researchers speculate that upright crops such as corn will appear brighter in vertically polarized images than in horizontally polarized images, enabling them to be distinguished from horizontally growing crops, such as alfalfa.

The Shuttle Imaging Radar project will eventually lead to an SAR imaging system in permanent earth orbit. Instead of having a dedicated satellite, an SAR will be placed on one of the free-flying platforms that will be orbited as part of NASA's space station program. Because the free flyer will be in a polar orbit, the SAR will be capable of imaging the entire planet. Before it is placed aboard the free flyer, however, the SAR hardware will be carried in a Space Shuttle and tested under the designation SIR-D.

Space-based SAR imaging systems will be used for more than just earth observation. In 1988 NASA will launch the Venus Radar Mapper, a space probe that will use an SAR to map the entire surface of that cloud-covered planet. There is even talk of a Saturn space probe that might carry an SAR to image the surface of Titan, Saturn's largest moon.

Observing our own planet, however, will be the most important—as well as the most lucrative—use for SAR imaging systems. According to *Space*, a newsletter published by Shearson, Lehman Bros. (New York) and the Center for Space Policy (Cambridge, Mass.), the international market for orbital earth images and data is expected to reach $2 billion annually by the turn of the century. If this forecast comes true, SAR radar imaging is certain to be an important part of the market.

Robert G. Nichols, formerly a software documentation specialist at the Johnson Space Center, writes frequently on aerospace topics.

Campus discounts irk computer retailers

Universities say they are simply trying to provide the academic community with an increasingly important educational tool at the lowest possible price. But their sales of heavily discounted microcomputers are prompting computer retailers to complain to the courts and state legislatures that academe is stealing their market.

The schools defend their computer sales as being no more an infringement on the private sector than campus bookstores, which have long supplied the university community with more traditional classroom goods. Moreover, they claim, such activities are fueling the growth of a campus microcomputer market from which retailers can benefit through sales of software and peripherals.

But in a college town where a large portion of the inhabitants work for or attend the university, discounted offerings may cut deeply into the local computer stores' market. And not only do they lose faculty and students as customers, contend computer retailers, but a gray market often arises in which machines are bought from the university at a discount and resold at a profit. "It's not fair that a publicly supported institution should compete with a privately owned business," says Jeff Inwood, owner of a Computerland store in Ann Arbor, Mich.

Underlying the problem are the special deals that most computer makers offer to educational institutions. IBM discounts its micros 20–37%, depending on quantity and model. A group of 24 major universities known as the Apple Consortium can buy Apple computers for a whopping 60% off; other schools are given more modest, but still substantial, price breaks.

Virtually all universities limit discount sales to faculty, students, and staff. The buyer is typically required to sign a statement that the machine is for personal use and that it will not be resold within two years. Violations are punishable by suspension or dismissal and restitution of profits.

Universities report few violations, but retailers say that's because the schools aren't looking. "We get people in here every day asking if we want to buy a computer cheap," says Ronald Golesh, president of Madison, Wis., retailer Computronics. He suspects that the machines come from the University of Wisconsin but says he can't check because the school will not release serial numbers.

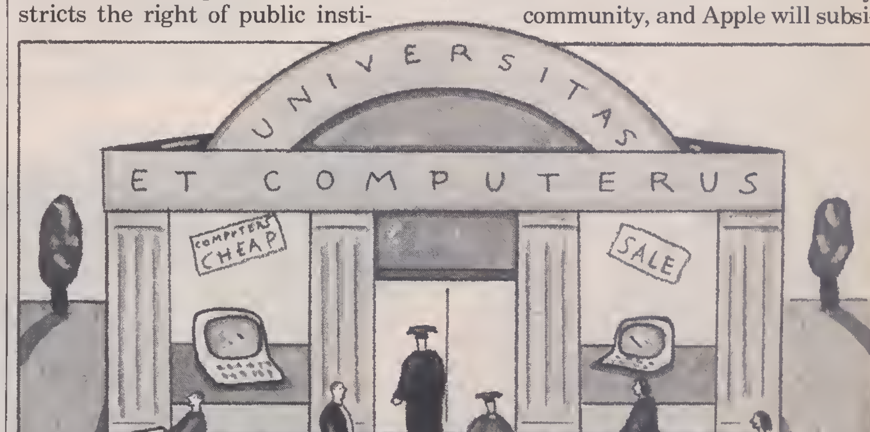
The controversy has erupted into legal skirmishes in several campus communities. In Madison, Computronics sued the U. of Wisconsin after the school began selling Macintoshes in 1984. Computronics charged that by selling cut-rate computers, the university and Apple were violating state minimum markup and fair-dealership laws as well as the Robinson-Patman Act, a federal antitrust law that prohibits manufacturers from charging different retailers different prices. Golesh says that his store must pay $1450 for a Macintosh with 128 kilobytes of memory, whereas the school can buy the same machine for $1226.

The university and the state attorney general's office argued that an exemption of nonprofit organizations in the federal act permits such university programs. The issue was never decided, however, because the U.S. District Court judge dismissed the case against the university on an unrelated technicality. Golesh, who says he spent $35,000 in legal fees, declined to pursue the case further.

In another lawsuit, four retailers accused the University of Illinois (Urbana) of violating a state law that restricts the right of public institutions to compete with private business. As a result of the suit, the school closed its computer store and designated local retailers to handle the education trade. University staff and students still receive a 30% discount at those stores, which make a modest profit, says Howard Diamond, assistant vice-chancellor for student affairs. The compromise did not please everyone, though; in October another lawsuit was filed against the school. Inwood's Computerland store in Ann Arbor has become embroiled in a similar dispute, which so far has stayed out of the courts.

In Wisconsin, Michigan, and several other states, retailers are lobbying for legislation that would forbid universities to compete with the private sector. Retailers are also pressuring the computer manufacturers, who have permitted the situation to occur by bypassing their own dealers to sell directly to universities. For example, the Ann Arbor Computer Dealers Association, which formed in response to the university problem, is considering a boycott of some computer makers who give price breaks to universities.

The controversy is forcing some changes, however. Beyond the 200 or so existing agreements, Apple will no longer allow universities to sell its computers, according to company spokesperson Kathleen Dixon. Under Apple's new policy (instituted last October), a school must name a local retailer to serve as "installing dealer." This store will discount its machines for the university community, and Apple will subsi-



CATHARINE BENNETT

dize the store with a small rebate (5–7% of purchase price) on each computer sold. But retailers are less than delighted with the arrangement. "It's like putting a Band-Aid on open-heart surgery," grumbles one shopkeeper.

Hard evidence of such mortal wounds is hard to find, however. The Association of Better Computer Dealers, a Chicago-based trade group that loudly opposes university sales of computers, presents no statistics to verify lost sales. Still, individual retailers claim drastic reductions. Computronics president Golesh, for example, reports that sales fell from about 15 Macintoshes a month before the U. of Wisconsin store opened, to zero after. And while total sales have doubled in the past year, the store's profit margin has sunk from 30% to 11% as a result of price cutting necessary to compete with the university. Such pressures have closed three computer stores in Madison since the school began selling computers, says Golesh.

Many school officials claim that lost retail business is due more to a general industry slump than to any university discount program. They contend that their programs are actually expanding the market. "We have 6000 PCs on campus," says Wayne Donald, assistant vice-president for computers and information systems at Virginia Polytechnic Institute and State University (Blacksburg), one of several schools that require science and engineering students to own microcomputers. "That's a lot of diskettes." Retailers assert, however, that their prime sale is the initial hardware and that most users get their extras from budget mail-order houses.

Nevertheless, some universities seem to be generating enough microcomputer business to go around. The number of computer stores in Ithaca, N.Y., for example, has tripled since Cornell opened its store, says a university official. And in the year since Virginia Tech began selling IBM PCs at a discount, several computer stores have opened in Blacksburg—a community that previously had none. □

—Tammi Harbert

Adding pep to small engines

The popularity of automotive turbochargers may sink as rapidly as it rose if alternate means of boosting engine power perform as well as advocates claim. The new challengers are superchargers and multivalves, which have appeared in the past year to compete for a piece of the growing market for small, high-horsepower engines.

Like turbochargers, superchargers and multivalve configurations dramatically improve power output by allowing the engine to "breathe" more effectively, thus yielding more oxygen for combustion. Both turbochargers and superchargers work by compressing air prior to its intake by the cylinders. In a turbocharger, the compressor is driven by a turbine spinning from the force of outrushing exhaust gas. Superchargers recycle engine power; the compressor runs off a belt, chain, or set of gears connected to the drive shaft.

Multivalve engines take a different approach, adding oxygen to the engine by simply increasing the area through which the air/fuel mixture enters and exhaust gas exits. Whereas common engines use only one intake and one exhaust valve per cylinder, most multivalves have two intake and two exhaust valves per cylinder—a total of 16 valves for a four-cylinder powerplant.

All three methods have been around as long as the automobile. But until the small-engine boom, only turbochargers had been extensively proven, through use on heavy diesels. Turbos thus became the preeminent means of boosting power in small engines in the early 1980s, when automakers scaled down car and engine sizes to meet government fuel-economy mandates.

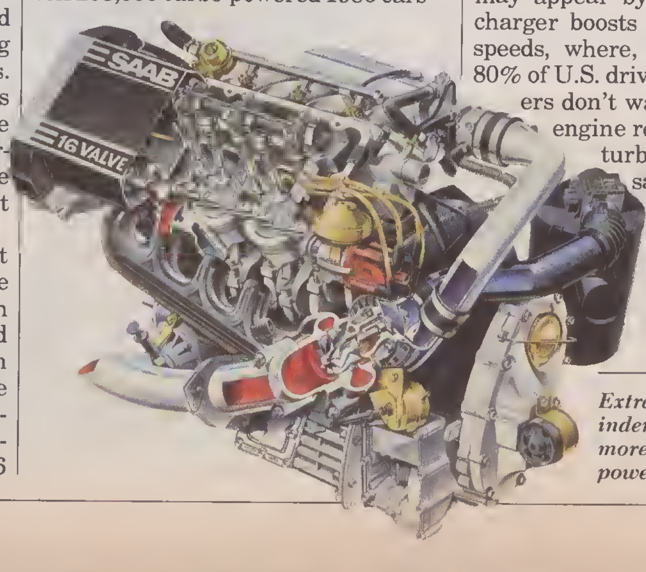
"The turbocharger was the quick, easy, and efficient way to get a high-performance engine," explains Scott D. Harvey, engineering manager at Chrysler's development center in Santa Fe Springs, Cal. Chrysler expects to sell 238,000 turbo-powered 1986 cars—more than Ford and GM combined.

But while turbocharging has been the quickest route to getting peppy performance out of small engines, automakers are beginning to admit that it's not necessarily the best. For starters, turbos are expensive—adding $628, for example, to the sticker price of the Dodge Lancer. What's more, turbos require extra maintenance, which if neglected (as it frequently is by U.S. auto-owners) can lead to dependability problems.

Most troublesome, however, is turbo lag—a brief but annoying delay in boost that occurs at low engine speed, when exhaust-gas pressure is too low to whip the compressor into action. The driver must endure sluggish, small-engine acceleration for several seconds, until the turbo kicks in and raises horsepower by as much as 50%.

The quick response provided by superchargers and multivalves has led to their recent surge in popularity. Imports are leading the way; 16-valve versions of the Saab 900S, VW Scirocco, and Toyota Celica are now available in the United States. Detroit, however, is not far behind. GM already plans a multivalve engine for the upcoming Reatta, Buick's high-performance "image" car. Ford is readying a 24-valve, six-cylinder design for its new Taurus and Sable models. Chrysler is developing similar engines in partnership with Italian automaker Maserati, and plans to introduce a sports car with multivalves in 1987.

Superchargers are just beginning to appear on the automotive horizon. Last fall Toyota introduced in Japan a supercharged version of its Crown luxury car. Volkswagen's development of superchargers is also far advanced. In the United States, Ford is working with Eaton on a supercharger that may appear by 1989. Eaton's supercharger boosts output at low engine speeds, where, the company claims, 80% of U.S. driving takes place. "Drivers don't want to wait until their engine revs up to 3000 rpm for turbo boost to kick in," says John W. Yakimow, engineering manager of Eaton's proving grounds in Marshall, Mich. Motorists need quick power, he points out, to merge with ex-



Extra valves let Saab's 4-cylinder turbo engine breathe more oxygen in order to boost power.

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Thus, small-engine potential is growing substantially. One Chrysler test car reaches 225 horsepower with four cylinders. Harvey points out, however, that today's lightweight front-drive cars are not engineered to handle that much power. Four-wheel traction will be needed to hold these small cars to the road as engine output grows. ☐

—Jeffrey Zygmont

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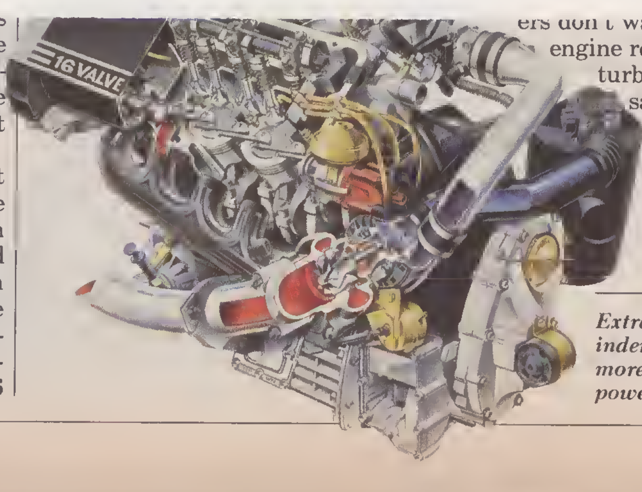

ers don't want to wait until their engine revs up to 3000 rpm for turbo boost to kick in," says John W. Yakimow, engineering manager of Eaton's proving grounds in Marshall, Mich. Motorists need quick power, he points out, to merge with ex-

Extra valves let Saab's 4-cylinder turbo engine breathe more oxygen in order to boost power.

pressway traffic or to dart across a wide intersection.

Eaton says its supercharger is as fuel-efficient as a turbo. That's an important point, because turbochargers are often touted for their use of "free" exhaust-gas energy while superchargers are said to scavenge engine power. But in fact, turbos create back pressure that fights piston motion during the exhaust stroke, cutting efficiency. A GM study revealed that a Chevrolet Chevette with a 1.6-liter, four-cylinder engine suffered an average city/highway fuel-economy loss of 2% both with a turbo and with a supercharger. The points on which GM found superchargers inferior to turbochargers—durability, packaging, and noise—are being addressed by Eaton in an eight-year, $5 million development program. For example, Eaton has designed a supercharger with a self-contained oil supply to maintain lubrication regardless of the condition of the engine oil, thus prolonging operating life.

While both superchargers and turbochargers require the addition of costly equipment, multivalve engines excel in their simplicity. "The big advantage of multivalves is cost," explains Chrysler's Harvey. "Once you get the engine tooled and in production, it is less expensive," as long as production runs remain high. Although multivalve engines generally don't have the power of turbocharged or supercharged engines, Chrysler's multivalve prototypes approach the 50% power boost obtained with turbochargers, says Harvey.

Multivalves also permit the addition of a turbo or supercharger, considerably compounding the performance gain. Harvey envisions an engine performance hierarchy that begins with multivalves at the first level, steps up to multivalve/turbo combinations, and above that, to combination engines with intercoolers. Already used in some turbocharged autos, intercoolers are radiator-like heat exchangers that cool the compressed air. Its lower temperature prevents engine knock—the damaging early ignition of fuel—thereby allowing higher boost.

Thus, small-engine potential is growing substantially. One Chrysler test car reaches 225 horsepower with four cylinders. Harvey points out, however, that today's lightweight front-drive cars are not engineered to handle that much power. Four-wheel traction will be needed to hold these small cars to the road as engine output grows. □

—Jeffrey Zygmont

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Information sources for topics covered in our feature articles.

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TECHSTARTS

Emcore:

GROWING GaAs CRYSTALS

As gallium arsenide (GaAs) integrated circuits—chips able to operate many times faster than those made of silicon—move closer to commercialization, chip makers are beginning to need substantial supplies of this still-exotic semiconductor. Emcore produces equipment for growing precisely controlled GaAs wafers, based on a technique called metal organic chemical vapor deposition. The company's equipment can deposit material one molecular layer at a time, creating, for example, a wafer composed of alternating compounds. Emcore also fabricates wafers to custom specifications and performs materials analysis under contract. Although many GaAs chip makers, such as AT&T and Rockwell in the United States and Sumitomo and Nippon Telegraph & Telephone in Japan, already make their own wafers, Emcore hopes to become a second source for some of their materials.

Financing: $2 million in venture capital from individual investors.

Management: The company's executive staff, Norman E. Schumaker, Wilfried R. Wagner, and Richard A. Stall, came from the semiconductor materials development group at nearby AT&T Bell Labs. Company founder Schumaker is chairman and president, Wagner is VP for systems development, and Stall is VP for materials development.

Location: 111 Corporate Blvd., South Plainfield, NJ 07080, (201) 753–1311.

Founded: October 1984.

Visage:

VIDEO THAT FOLLOWS ORDERS

Although you still can't carry on an actual conversation with your TV set, Visage's interactive videodisc and personal computer systems make it seem almost possible. They're designed to let users view recorded videos in any sequence and manipulate overlaid animated computer graphics—all to the accompaniment of hi-fi stereo sound. Visage is marketing its systems for use in corporate training, point-of-purchase displays, and equipment maintenance documentation. In addition to selling hardware, the company produces software to help customers design their own applications. Most of Visage's competition is from start-ups such as Interactive Training Systems and Continuous Learning, but established companies like Kodak are already dabbling in such systems for internal use and may branch into sales as well. Visage's biggest contract so far is with the programmable-controller division of Gould, which plans to develop its own customer-training software for Visage's system.

Financing: $5.26 million in venture capital financing from investors including Venture Founders, Memorial Drive Trust, First Chicago, Turner Revis Associates, and Arthur D. Little Enterprises.

Management: Philip V. W. Dodds, founder, chairman, and president, was VP of engineering at Kurzweil Music Systems, where he managed development of a computerized keyboard instrument. Leo P. Keightley, cofounder and director of engineering, was a research engineer for ARP Instruments/Fender Musical Research and Development.

Visage is aiming its video systems at merchandise displays and corporate training, says founder Philip V. W. Dodds.

Location: 12 Michigan Dr., Natick, MA 01760, (617) 655–1503.

Founded: May 1983.

Immunex:

HELPING THE IMMUNE SYSTEM FIGHT DISEASE

Some of the most promising substances currently under evaluation as weapons against cancer and other serious diseases are lymphokines, a group of immune-system regulatory hormones that help protect the body against infection, inflammation, and malignancy. Immunex uses recombinant-DNA technology, cell fusion, and proprietary techniques of its own to produce lymphokines such as interleukin-1 and -2 (IL-1 and -2) and several types of colony stimulating factor (CSF). Staying out of manufacturing for now, the company has an agreement with Hoffmann-La Roche for commercialization of IL-2, with Syntex for IL-1, and with Behringwerke, a division of Hoechst AG, for CSF. With some clinical trials under way and others about to begin, lymphokines—also produced by Genentech, Cetus, and several other firms—could become a large-scale market before the end of the decade.

Financing: $2.5 million in venture capital from investors including Cable, Howse & Cozadd, Mayfield Partners, New Enterprise Associates, and Rothschild. An initial public stock offering in July 1983 of 1.5 million shares at $11 per share, underwritten by Cable, Howse & Ragen, and Robertson, Colman & Stephens, resulted in net proceeds of $15.2 million. The OTC stock symbol is IMNX.

Management: The firm's founding scientists, executive VPs Steven Gillis and Christopher Henney, were immunology researchers at the Fred Hutchinson Cancer Research Center in Seattle and were on the microbiology and immunology faculty at the University of Washington. Stephen A. Duzan, cofounder, president, and CEO, was executive VP of North Star Ice Equipment and earlier was president and CEO of Cello Bag Co.

Location: 51 University St., Seattle, WA 98101, (206) 587–0430.

Founded: July 1981.

DILIP CHAUHAN

BETTER CHIPS THROUGH CHEMICAL VAPORS

Higher-density circuits require new thin-film processes

The intricate conductive paths essential to the functioning of silicon chips have traditionally been made of aluminum. But aluminum has certain limitations that become more pronounced as circuit densities increase in very small, high-speed chips; as temperature rises, for example, aluminum expands more rapidly than the silicon substrate, which can lead to cracking.

Aluminum can still be used in the upper layers of such devices, but other materials must comprise the narrow circuit lines in the critical lower layers. The physical evaporation process applied to aluminum cannot be efficiently used with these metals, such as tungsten, molybdenum, titanium, or tantalum, because their melting points are much greater than that of aluminum. But chemical vapor deposition (CVD)—a lower-temperature process—can be used with gases derived from these materials. In this technique, employed by fabricators such as National Semiconductor, Intel, AMD, and Motorola, a gas such as tungsten hexafluoride is placed into a chamber with silane (a gas derived from silicon) and silicon wafers. As they are heated, the gases react evenly throughout the chamber to form a foglike silicide vapor that condenses in a very thin layer onto the wafers.

Although the semiconductor industry is presently in a slump, with fabrication in 1985 expected to drop 15–20% from the previous year, the continuing demand for greater performance and higher speed in circuits is fueling the development of ever-smaller chips. Consequently, C. H. Kline (Fairfield, N.J.) predicts that demand for CVD equipment will grow from an estimated $200 million in 1985 to $650 million by 1989—an average annual growth rate of 34% during a period when the electronics industry as a whole should grow only 15% a year. However, investors should keep in mind that these high growth rates are not likely to appear until late 1986 or early 1987; until then, the semiconductor market will probably remain flat.

The metal silicide CVD market is dominated by Genus (Mountain View, Cal.), which accounts for two-thirds of all equipment sales. Among smaller firms, several are basing their growth on more efficient variations on the CVD process and on the integration of other fabrication steps with CVD. These companies include Applied Materials (Santa Clara, Cal.), Phoenix Materials (Kittanning, Pa.), and Advanced Semiconductor Materials (ASM) International (Bilthoven, the Netherlands).

Applied Materials (OTC: AMAT) is the leader in several semiconductor processes, such as epitaxial silicon deposition and plasma etching, that are used along with CVD to manufacture high-density chips. Within a year, Applied Materials expects to commercialize one or more alternatives to the heat-based systems that are generally used to react gases in present CVD equipment. These alternatives—in which energy is imparted to the gases by a plasma, a magnetic device, or an energetic light source—improve chip yields and profits by reducing the amount of heat needed for processing.

Estimated sales for fiscal 1985 are $200 million, compared to $168 million in 1984. Net income for FY85 is estimated at $12 million, earnings per share at $1.95; in 1984, profits were $13 million and earnings per share $2.07. Profits are down, despite increased revenue, because the company has been launching new products with high start-up costs.

Reaction chamber of ASM's plasma-enhanced CVD system.

While the semiconductor industry is moving toward fully automated, continuous fabrication of chips, CVD is still a batch process. But **Phoenix Materials** (OTC: PNCS) is working on a continuous CVD system that would improve productivity. The company is currently seeking funds from investors to finance more R&D on this concept.

Phoenix Materials' current CVD products can be used not only in chip fabrication, but for non-electronic coating applications as well—for extending the service life of cutting tools, for example. The company also produces chemical-fume scrubbers and pH control systems, and owns Pensilco, a silicon-wafer manufacturer.

While revenues were reported at $4 million in 1985, with a loss of $64,000 and a 6¢ loss per share, this is a dramatic improvement over 1984's loss of 61¢ per share on revenues of $2 million, with a net loss of $661,000.

ASM International (OTC: ASMIF) makes wafer-processing, assembly, and encapsulation equipment, as well as systems used in fiber optic manufacturing. CVD equipment from this firm is especially suited for fabricating chips that use both aluminum and metal silicides, as it can process silicides at temperatures well below the melting point of aluminum. ASM may also gain a jump on the market for 1- and 4-megabit chips because it specializes in titanium silicides for circuit materials. Since this material has the lowest electrical conductivity among all silicides, it is being actively investigated for use in such circuits.

Due to overall market conditions, sales for 1985 remained relatively flat—estimated at $100 million, compared with $99 million in 1984. Net income for 1985 should be $6.5 million, with 94¢ earnings per share; in 1984, profits were $6.6 million, with the same earnings per share.

by Biron Lim

Biron Lim is a senior consultant specializing in electronic chemicals at C. H. Kline, a market research and consulting firm for the chemical industry.

ASM INTERNATIONAL

Pictured with Cajun delicacies are Chef's Michael Hall, Patrick Mould and Joseph Gonsoulin, gold medal winners of the Culinary Classic, held by Les Chefs des Cuisines de Acadiana.

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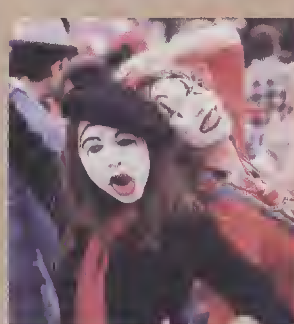

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